DEPARTMENT OF DEFENSE SPACELIFT IN A FISCALLY CONSTRAINED ENVIRONMENT

A thesis presented to the Faculty of the U.S. Army Command and General Staff College in partial fulfillment of the requirements for the degree

MASTER OF MILITARY ART AND SCIENCE
Military Space Applications

by

MAURICE H. MOORE, Maj, USAF
B.A., West Virginia University, Morgantown, West Virginia, 1998
M.S., University of Nevada, Las Vegas, Nevada, 2006

Fort Leavenworth, Kansas
2011-02

REPORT DOCUMENTATION PAGE					Form Approved OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From - To)*
16-12-2011	Master's Thesis	FEB 2011 – DEC 2011

4. TITLE AND SUBTITLE

Department of Defense Spacelift in a Fiscally Constrained Environment

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Moore, Maurice H., Maj

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

U.S. Army Command and General Staff College
ATTN: ATZL-SWD-GD
Fort Leavenworth, KS 66027-2301

8. PERFORMING ORG REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for Public Release; Distribution is Unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The Department of Defense (DoD) has come under increased scrutiny in recent years due to poorly performing acquisition programs and massive budgetary requirements. In addition to a challenging economy, prolonged conflict since 2001, and a US national debt that exceeded $14 trillion at the end of 2010, the DoD is looking to reduce the overall budget by nearly a trillion dollars over the next ten years. One of the most critical areas the DoD has failed to successfully manage acquisitions is within the portfolio for space systems. One aspect of this portfolio includes the acquisition of launch services under the Evolved Expendable Launch Vehicle program to enable space-based capabilities. This program was initiated in the 1990s and was meant to replace expensive DoD-exclusive launch programs by teaming with commercial business to lower launch costs. Unfortunately, launch costs under the current program are on the rise and the spacelift industrial base continues to shrink. Because of these economic and programmatic challenges, this study aims to specifically evaluate if DoD spacelift requirements can be achieved in a more efficient approach without reducing the success rates or launch production rates currently realized under the Evolved Expendable Launch Vehicle program.

15. SUBJECT TERMS

Evolved Expendable Launch Vehicle (EELV), Department of Defense (DoD) spacelift, United Launch Alliance (ULA), Atlas V, Delta IV, National Aeronautics and Space Administration (NASA)

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			**19b. PHONE NUMBER** *(include area code)*
(U)	(U)	(U)	(U)	159	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

MASTER OF MILITARY ART AND SCIENCE
THESIS APPROVAL PAGE

Name of Candidate: Major Maurice H. Moore

Thesis Title: Department of Defense Spacelift in a Fiscally Constrained Environment

Approved by:

____, Thesis Committee Chair
Lt Col Michael A. Creighton, M.S.

____, Member
Albert C. Stahl, M.M.A.S.

____, Member
Tony R. Mullis, Ph.D.

Accepted this 16th day of December 2011 by:

____, Director, Graduate Degree Programs
Robert F. Baumann, Ph.D.

The opinions and conclusions expressed herein are those of the student author and do not necessarily represent the views of the U.S. Army Command and General Staff College or any other governmental agency. (References to this study should include the foregoing statement.)

ABSTRACT

DEPARTMENT OF DEFENSE SPACELIFT IN A FISCALLY CONSTAINED ENVIRONMENT, by Major Maurice H. Moore, 159 pages.

The Department of Defense (DoD) has come under increased scrutiny in recent years due to poorly performing acquisition programs and massive budgetary requirements. In addition to a challenging economy, prolonged conflict since 2001, and a US national debt that exceeded $14 trillion at the end of 2010, the DoD is looking to reduce the overall budget by nearly a trillion dollars over the next ten years. One of the most critical areas the DoD has failed to successfully manage acquisitions is within the portfolio for space systems. One aspect of this portfolio includes the acquisition of launch services under the Evolved Expendable Launch Vehicle program to enable space-based capabilities. This program was initiated in the 1990s and was meant to replace expensive DoD-exclusive launch programs by teaming with commercial business to lower launch costs. Unfortunately, launch costs under the current program are on the rise and the spacelift industrial base continues to shrink. Because of these economic and programmatic challenges, this study aims to specifically evaluate if DoD spacelift requirements can be achieved in a more efficient approach without reducing the success rates or launch production rates currently realized under the Evolved Expendable Launch Vehicle program.

ACKNOWLEDGMENTS

I extend special thanks to the members of my committee and the space operations instructors for their encouragement and assistance in writing this thesis. The superb guidance and feedback provided by Lt Col Michael Creighton, Dr. Tony Mullis, and Mr. Albert Stahl was invaluable. All three committee members provided unmatched support, perspective, and counseling required to complete this study while compelling me to expand my knowledge and understanding of Department of Defense spacelift. Additionally, the space operations instructors of the US Army Command and General Staff College also aided in focusing and evaluating my research. Through the diligent support by LTC Clifford Hodges, Mr. Tom Gray, Maj Jason Burch, and Maj Nicholas Martin, this thesis would not have been possible.

Many thanks to the Staff Group 1B teaching team. This includes Mr. Albert Stahl (Staff Group Advisor and DTAC instructor), Dr. Nicholas Riegg (DJIMO), Mr. Joseph Babb (Section 1 Leader and DJIMO instructor), Mr. Robert Bayless (DLRO), Mr. Jonathan “Dwayne” Beasley (DCL), and Mr. George Stephenson (DMH). Each of these instructors provided leadership, advice, and unique perspectives that supported in areas of DoD acquisitions, innovation, and their application to military space operations.

Finally, I could not have been successful in conducting and completing this study without the unparalleled support from my wife, Lea, and our daughter, Chantell. Their commitment, patience, and understanding allowed me to complete this research and succeed during the academic year. More importantly, their enduring love, support, and encouragement have enabled me to succeed and achieve personal and professional accomplishments. They have truly made my career and this academic year possible.

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ACRONYMS

AFB	Air Force Base
AFS	Air Force Station
AFSPC	Air Force Space Command
AG	*Aktiengesellschaft*
DoD	Department of Defense
EELV	Evolved Expendable Launch Vehicle
FAA	Federal Aviation Administration
FY	Fiscal Year
GPS	Global Positioning System
GTO	Geosynchronous Transfer Orbit
ILS	International Launch Services Incorporated
JP	Joint Publication
LEO	Low Earth Orbit
NASA	National Aeronautics and Space Administration
RDT&E	Research, Development, Test, and Evaluation
SA	*Société Anonyme*
SES SA	*Société Européenne des Satellites Société Anonyme*
SpaceX	Space Exploration Technologies Corporation
STS	Space Transportation System
ULA	United Launch Alliance
US	United States of America
USAF	United States Air Force

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CHAPTER 1

INTRODUCTION

> Acquisition excellence requires a combination of agile decision making and disciplined execution to leverage technology while meeting cost, schedule, and performance expectations. Major system acquisitions provide important new capabilities to meet future missions. Being able to deliver capability cost-effectively when it is needed improves mission effectiveness, provides leadership with flexibility in making investments, and precludes gaps in necessary capabilities.
>
> — Dennis C. Blair, *2009 National Intelligence Strategy*

The United States of America (US) has been involved in a variety of military engagements and humanitarian efforts at home and abroad since 2001. During this time, the Department of Defense (DoD) has worked diligently in developing, acquiring, operating, sustaining, and fielding capabilities to execute the US military instrument of power. The DoD has come under increased scrutiny in recent years due to massive budgetary "requirements" within a very constrained fiscal environment (Department of Defense News Release 2011). Additionally, members of the US government are looking to significantly reduce US military presence and involvement in current conflicts abroad (US House of Representatives 2011) and are seeking to reduce funding across all segments of the US government (Kauffman and Spoth 2010). This shift in focus is an effort to reduce the US national debt that exceeded $14 trillion at the end of 2010 (US Department of Treasury, Bureau of the Public Debt 2010). These events, coupled with potentially significant funding cutbacks on the horizon for the DoD, bring into question whether the DoD can accomplish its mission more efficiently and cost effectively. The *Fiscal Year 2012 (FY12) US Air Force (USAF) Posture Statement* highlights the fact that the USAF "remains mindful of our Nation's budgetary challenges and fiscal constraints,

because fiscal responsibility is a national security imperative" (Donley and Schwartz 2011, 1). It further states that the USAF is committed to five particular acquisition priorities to address capabilities for the current conflicts with the needs of emerging threats and challenges. These include: the aerial tanker recapitalization; F-35 program restructure and F-16 service life extension program; intelligence, surveillance, and reconnaissance systems; long-range strike family of systems; and space systems and launch acquisition strategy (Donley and Schwartz 2011, 1). Because of the increased budget pressures on the DoD, this paper aims to specifically evaluate if DoD spacelift requirements can be achieved in a more efficient approach without reducing the success rates or launch production rates currently realized under the Evolved Expendable Launch Vehicle (EELV) program. In order to evaluate if spacelift can be performed more efficiently, one must first understand the significance and national security implications provided by space-based capabilities.

Significance of Space-Based Capabilities

Space-based capabilities have become increasingly important since the launch of Sputnik I by the Union of Soviet Socialist Republics in October 1957 (Morgan 2010, 8). For over 50 years, manmade satellites have furthered our understanding of the universe; enabled global telecommunications and monetary transfer; refined precision navigation and timing; advanced research and development; and permitted numerous commercial and military applications. As noted in the preface of the *National Security Space Strategy*, "space systems allow people and governments around the world to see with clarity, communicate with certainty, navigate with accuracy, and operate with assurance" (Gates and Clapper 2011, i). Within the latest *National Space Strategy*, President Barack

Obama notes “our space capabilities underpin global commerce and scientific advancements and bolster our national security strengths and those of our allies and partners” (The White House 2010a, 31). Space-based capabilities are an indispensable part of our commercial and military activities.

Originally, space-based capabilities were limited to a small number of countries. Today, space-based assets are used globally by virtually all nations and even non-state actors. Specific orbits around the Earth have become increasingly crowded and competitive. As demonstrated in figure 1, there are close to 60 nations and government consortia that own and operate satellites (Gates and Clapper 2011, 2). This does not include the numerous commercial or academic satellite operators that also exist. American dependence on space-based assets in our daily lives has also grown significantly over the years.

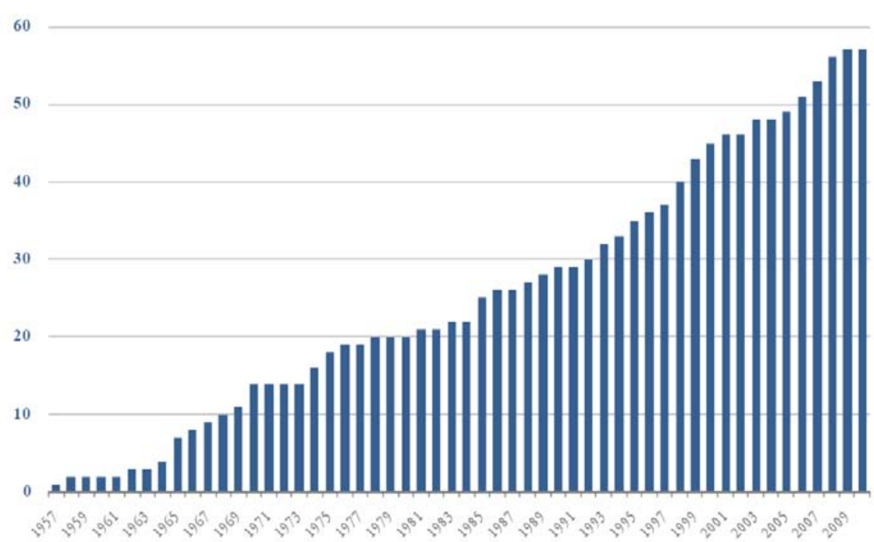


Figure 1. Number of Nations and Government Consortia Operating in Space
Source: Robert M. Gates and James R. Clapper, *2011 National Security Space Strategy* (Washington, DC: Government Printing Office, January 2011), 2.

Unlike sovereign airspace, the space domain is open to any nation as agreed upon in Article II of the *1967 United Nations Outer Space Treaty* (United Nations Publication 2002, 4). The DoD defines the space domain as a medium like the land, sea, and air within which military activities are conducted to achieve US national security objectives (Chairman of the Joint Chiefs of Staff 2009, ix). Where space begins has not been explicitly delineated in any treaty or DoD publication. This is due to the variety of activities that occur within Earth's atmosphere and the potential legal implications of these activities (examples include the idea of a commercial space plane and test aircraft like the X-15 that conducted tests around 62 miles above the Earth). It is generally accepted that space begins around 100 kilometers above the Earth, at an altitude where objects can safely orbit (Shostak 2004). Although every nation is permitted peaceful use of space, over the last decade the world has experienced and witnessed nations and non-state actors (whether intentionally or unintentionally) degrading or destroying space-based capabilities. Such instances include China's January 2007 anti-satellite test that destroyed an aging Chinese weather satellite in Low Earth Orbit (LEO) (MSNBC.com Staff and news service reports 2007), localized jamming of space-based transmissions or capabilities to ground users (Sung-Ki 2011), and even degradation of satellite data or transmissions due to frequency interference (Chow 2010). A recent example of a space-based capability that was temporarily degraded was the recent intentional jamming of communication satellites supporting North Africa customers. Commercial mobile satellite service operator Thuraya Telecommunications announced on 25 February 2011 that they had been subjected to "harmful and intentional interference in Libya" for a period of seven days (Ebrahim 2011). This interference affected both data and voice

communications within Libya and the surrounding area. The purpose of the attack was believed to limit telecommunication services into and out of Libya during that timeframe. These examples highlight the additional challenges and threats the US must recognize and counter in the current global environment. The *National Security Strategy* states the US must safeguard the global commons (sea, air, cyberspace, and space domains) in order to keep “strategic straits and vital sea lanes open, improving the early detection of emerging maritime threats, denying adversaries hostile use of the air domain, and ensuring the responsible use of space” (The White House 2010a, 50). Because of our dependence on space-based capabilities and increasing threats in the space domain, the significance and importance spacelift plays within the global commons is clear.

Recent DoD Spacelift History, National Policies, and EELV Acquisition

The first National Aeronautics and Space Administration (NASA) Space Shuttle launch occurred in April 1981 (Dumoulin 2001a). Following the successful initiation of the Space Transportation System (STS) with a positive first flight demonstration and a day after a second mission launch, President Ronald Reagan issued National Security Decision Directive 8 that designated the STS (i.e., NASA Space Shuttle Program) as the primary launch system for military and government payloads (George C. Marshall Institute 1981, 1). This set in motion the focus of DoD spacelift onboard NASA Space Shuttles but it wasn’t meeting expectations for cost and launch rates. Due to ongoing launch delays because of the limited numbers of STS launches, the DoD sought to pursue complimentary options to launch national security payloads. Following the first DoD classified payload deployment with the STS, President Reagan signed National Security Decision Directive 164 in February 1985 directing the DoD to continue using the NASA

Space Shuttle as the primary launch system (committing at that time to at least a third of the STS missions over a period of ten years) but to also pursue an “improved assured launch capability that will be complementary to the STS” (George C. Marshall Institute 1985, 1). The policy specifically directed the USAF to pursue expendable launch vehicles at a rate of two launches per year for five years.

Within a year of signing the National Security Decision Directive 164, the Space Shuttle Challenger disaster occurred in January 1986 (Dumoulin, 2001b). This single event grounded the STS and DoD spacelift until a formal accident investigation was concluded and investigation board recommendations were implemented. The STS program did not resume launch operations until September 1988 (Dumoulin, 2001c). Following the Challenger disaster, President Reagan issued National Security Decision Directive 254. It superseded National Security Decision Directive 164 and directed a new National Space Launch Capability based on a mix of the STS and expendable launch vehicles (George C. Marshall Institute 1986, 1).

The DoD pursued a number of programs focused on obtaining improved expendable launch capabilities. These included the Advanced Launch System program (1987-1990), the National Launch System program (1991-1992), and the Spacelifter program (1993). Each program achieved aspects of technical achievement but for a variety of reasons, failed to address the national spacelift needs (Kimhan et al. 1999, 86). One of the best examples of expendable launch capabilities was the venerable Delta II launch vehicle (as shown in figure 2 of the 24 March 2010 Delta II launch from Cape Canaveral Air Force Station (AFS), Florida). The DoD awarded The Boeing Company a contract for a Medium Lift Vehicle to specifically launch the latest Global Positioning

Satellite (GPS) constellation following the Space Shuttle Challenger disaster (The Boeing Company 2011a). Boeing designed and provided the Delta II launch vehicles and conducted the first launch in 1989. It served the DoD until 2009 with launch and deployment of the eighth and final GPS Block IIR-M satellite. The Delta II was only capable of delivering payloads weighing 4,680 lbs to Geosynchronous Transfer Orbit (GTO) or 11,970 lbs to LEO. As a result of its limited payload capacity, success achieved under the EELV program, and as a means to reduce the budget, the DoD concluded use of the Delta II in favor of only launching payloads through the EELV program. Because of the costs experienced in various spacelift programs in the early 1990s, Congress directed the DoD in 1993 to develop a Space Launch Modernization Plan with the ultimate goal of lowering the cost of spacelift (Saxer et al. 2002, 4).

Figure 2. Delta II Launch

Source: Space and Missile Center Public Affairs Office, “GPS IIR-20 successfully launches from Cape Canaveral,” *Air Force Print News Today*, Photo by Carleton Bailie, 24 March 2009, http://www.losangeles.af.mil/news/story.asp?id=123141115 (accessed 1 October 2011).

The Space Launch Modernization Plan identified four modernization options. They included sustaining existing launch systems, evolving current expendable launch systems, developing a new expendable launch system, or developing a new reusable launch system. Of the four options, the DoD gained approval to develop more advanced expendable launch systems. President William Clinton's Presidential Decision Directive/National Science and Technology Council Memorandum-4 identified the DoD as lead agency for "improvement and evolution of the current US expendable launch vehicle fleet" (George C. Marshall Institute 1994, 2). Following this policy, the DoD initiated the EELV program to address this requirement (Saxer et al. 2002, 4). The EELV program aimed to reduce heritage launch costs 25-50 percent through a drastic departure from a historically government-owned philosophy (i.e. government owned hardware and infrastructure) to a contracted launch service with government-accepted higher risk approach for launch vehicle acquisitions and launch operations (i.e. contractor owned hardware and contractor leased infrastructure).

Through the remainder of the 1990s, the EELV program went through a laborious acquisition strategy, initially involving four competitors that were narrowed to two, including a concept validation phase, pre-engineering and manufacturing development phase, and ultimately initiating the engineering and manufacturing development phase. While the DoD pursued the EELV program, the Commercial Space Transportation Advisory Committee projected in April 1997 that global demand for spacelift would be in the range of 30-40 annually due to anticipated launches required to support commercial satellite development for users like Iridium (Saxer et al. 2002, 5-6). This anticipated launch rate enabled the DoD to seek commercial cost sharing for EELV development and

strive for optimized launch operations and maintenance by enabling the launch service provider to perform those functions rather than the DoD. The revised acquisition strategy aimed to keep two competitors for the life of the program (rather than the anticipated selection of a single provider), to encourage vendor development cost sharing, and to leverage the rapidly growing commercial launch market to drive costs down (Kimhan et al. 1999, 87). In October 1998, the DoD awarded both The Boeing Company (Delta IV Family of Vehicles as illustrated in figure 3 with the 22 November 2010 launch of a Delta IV Heavy from Cape Canaveral AFS) and Lockheed Martin Corporation (Atlas V Family of Vehicles as illustrated in figure 4 with the 3 April 2009 launch of a Atlas V in a 421 configuration from Cape Canaveral AFS) EELV contracts for “Engineering and Manufacturing Development” and “Initial Launch Services.” Each company received only $500 million for further development (with the remainder of development paid out-of-pocket by the respective company) and approximately $72 million per launch (Boeing was awarded 19 launches with the initial contract and Lockheed Martin was awarded 9 launches) (Behrens 2006, CRS-7).

Unfortunately in 2000, the projections for global launch demand failed to materialize with the demand for commercial satellite communication capabilities significantly falling in favor of terrestrial fiber optics (Saxer et al. 2002, 15). Both contractors required renegotiated EELV contracts (Behrens 2006, CRS-7). As the commercial market dried up, the estimated prices for future launches increased along with the total cost of the EELV program (Government Accountability Office 2008, 7). Additionally, Boeing became involved in ethics violations pertaining to other DoD acquisition programs in 2003. This resulted in Boeing conceding seven existing launch

contracts to Lockheed Martin and being disqualified from three new launch contracts. Lockheed Martin developed a launch site at Vandenberg Air Force Base (AFB), California thus eliminating Boeing's west coast launch monopoly (previously the DoD only permitted Boeing to possess an active launch site at Vandenberg AFB due to the limited launches anticipated from California) (Behrens 2006, CRS-7).

Figure 3. Delta IV Launch
Source: Eric Brian, 45th Space Wing Public Affairs, "45th SW launches Delta IV-Heavy," 22 November 2010, http://www.patrick.af.mil/news/story.asp?id=123231921 (accessed 13 May 2011).

Figure 4. Atlas V Launch
Source: 45th Space Wing Public Affairs, "Satellite to enhance military communications launched," *Air Force Print News Today*, Photo by Pat Corkery, 4 April 2009, http://www.patrick.af.mil/news/story_print.asp?id=123142884 (accessed 13 May 2011).

In December 2004, President George W. Bush signed a new US Space Transportation Policy under National Security Presidential Directive-40 to supersede President Clinton‘s 1994 Presidential Decision Directive/National Science and Technology Council Memorandum-4. This new policy recognized the downturn in the demand for commercial launch services and directed the US government to "provide sufficient and stable funding for acquisition of US space transportation capabilities in

order to create a climate in which a robust space transportation industrial and technological base can flourish” (George C. Marshall Institute 2005, 2). This policy also directed the following:

> For the foreseeable future, the capabilities developed under the Evolved Expendable Launch Vehicle program shall be the foundation for access to space for intermediate and larger payloads for national security, homeland security, and civil purposes to the maximum extent possible consistent with mission, performance, cost, and schedule requirements. New US commercial space transportation capabilities that demonstrate the ability to reliably launch intermediate or larger payloads will be allowed to compete on a level playing field for US government missions. (George C. Marshall Institute 2005, 3-4)

In March 2005, the USAF finally removed suspensions imposed on The Boeing Company in 2003 allowing them to compete for government launch contracts (Behrens 2006, CRS-7). Additionally, the DoD revised the EELV contracting strategy in March 2005 to a cost-plus award fee contract for EELV Launch Capability and a fixed-price incentive fee contract for EELV Launch Services. This strategy enabled Boeing and Lockheed Martin to defray mission specific and infrastructure related costs to the government without having to assume the increased cost burden. This also enabled the DoD to gain more insight into contractor accounting than previous contracts permitted (Government Accountability Office 2008, 8).

In May 2005, Boeing and Lockheed Martin announced plans to formulate a 50-50 joint venture to consolidate their associated EELV launch services. This included consolidation efforts related to launch vehicle production, engineering, test, and launch operations (United Launch Alliance 2011c). The Federal Trade Commission ultimately approved the merger in October 2006 and by December 2006 they established United Launch Alliance (ULA) (Federal Trade Commission 2006). This merger was primarily an effort to drive cost savings (anticipated at $100-150 million annually) as a result of the

limited global launch market (Government Accountability Office 2008, 8). Since 2006, ULA has operated successfully and flawlessly in support of DoD and NASA missions. ULA has consolidated program management, engineering, test, and mission support functions at their corporate headquarters in Denver, Colorado. Launch operations between the product lines now have open communication, improved synergy, and refined operations by incorporating best-practices from both product lines. Launch vehicle hardware production and integration is also slowly being consolidated to Harlingen, Texas and Decatur, Alabama (Fleischauer 2011). The parent companies, Boeing and Lockheed Martin, maintain involvement with ULA by marketing, coordinating, and contracting commercial spacelift services (via Boeing Launch Services and Lockheed Martin Commercial Launch Services) with ULA subcontracted for launch operations (The Boeing Company 2011b) (Lockheed Martin Corporation 2011b). Although concerns arose with the formation of ULA and the potential adverse effects on domestic spacelift competition (including higher long-term prices and a loss of innovation), the DoD concurred with the merger (Watts and Harrison 2011). The Undersecretary of Defense for Acquisition, Technology, and Logistics (Kenneth Krieg) defended the merger by stating:

> The current and future commercial launch market, including the inability of U.S. firms to compete against foreign firms coupled with the low number of national security launches, makes it extremely difficult for two competing U.S. providers to maintain separate, competing, experienced workforces. ULA will offer two distinct families of launch vehicles with a single, more efficient workforce, thereby enhancing assured access to space. Launch presents significant risk to a payload, and fifty years of launch experience teaches that risk is reduced when the launch is supported by an experienced workforce with recent launch experience. The single ULA workforce will benefit from a launch tempo, defined as the number of booster cores built in the assembly line and launched per year, that would be greater than could be expected for either of the two competing workforces. (Krieg 2006)

Since August 2007, the DoD has designated the EELV program in the sustainment phase of the DoD acquisition lifecycle with limited additional development and relatively steady-state costs and performance (Air Force Financial Management and Comptroller 2011a, 05-68). Additionally, the *Air Force Space Command (AFSPC) Routine Spacelift Enabling Concept* of October 2007 extends the anticipated life of the EELV program an additional 10 years through 2030 (Air Force Financial Management and Comptroller 2011a, 05-68). In considering the historical events and policies that have shaped the EELV program, it is important to also understand the current guidance and roadmaps the EELV program must support.

Current DoD Spacelift Policies and Acquisition Reform

Two key goals US national space programs are striving to meet include "energizing competitive domestic industries" and "expanding international cooperation" (The White House 2010b, 4). The aim with this policy is to reinvigorate the US domestic industrial capability for space related systems and to reclaim US leadership for worldwide space systems development and procurement. As President Obama concluded:

> To maintain the advantages afforded to the United States by space, we must also take several actions. We must continue to encourage cutting-edge space technology by investing in the people and industrial base that develops them. We will invest in the research and development of next-generation space technologies and capabilities that benefit our commercial, civil, scientific exploration, and national security communities, in order to maintain the viability of space for future generations. And we will promote a unified effort to strengthen our space industrial base and work with universities to encourage students to pursue space-related careers. (The White House 2010a, 31)

One particular element associated with reinvigorating the domestic industrial base is legacy export controls. As mentioned in the *National Security Space Strategy*, export controls "can also affect the health and welfare of the industrial base, in particular

second-tier and third-tier suppliers" (Gates and Clapper 2011, 7). The US is revising legacy space-related technology export controls to promote US commercial sales and technological collaboration abroad, thus enabling domestic manufacturers to more easily compete in the global space-related market. This is congruent with the US position to actively promote partnerships with other space-faring nations and also promoting strategic partnerships with commercial entities in order to gain access to "more diverse, robust, and distributed set of space systems and provide easily releasable data" (Gates and Clapper 2011, 9). The ultimate objective with partnership and commercial reinvigoration is to stabilize costs, improve technological advancement, improve interoperability and compatibility, and promote mutual benefits across commercial and international partners. Although there are benefits in international partnerships, past space policies, including the most recent *National Space Policy,* all dictate that US government payloads will be launched by launch vehicles manufactured in the US to the maximum extent possible. Although partnership is desired, national policies will need to be evaluated closely to enable these opportunities.

As part of the FY10 and proposed FY11 budgets, the US government decided to retire the NASA Space Shuttle program and cancel the Space Shuttle replacement program known as Constellation (Malik 2010). Additionally, the Secretary of Defense has increased DoD-wide emphasis on improving acquisition and contracting procedures and oversight to enable agile and timely procurement (Gates 2008, 19). As a result, the US agencies involved with space-based capabilities are evaluating internal governance, investigating opportunities to team and collaborate within government, and finding ways

to reduce costs while continuing to pursue their respective strategic objectives within a limited budget.

As directed in section 2273 of Title 10 US Code, the DoD is responsible for sustaining the availability of at least two space launch vehicles capable of launching national security payloads while also maintaining a robust space launch infrastructure and industrial base (Office of the Law Revision Counsel, US House of Representatives 2011). Within the DoD, the Secretary of the Air Force is the lead Executive Agent for Space. Per the *FY12 US Air Force Posture Statement*, “the [Executive Agent] is charged with the integration and assessment of the DoD overall space program, the conduct and oversight of long-term space planning and architecture development, and the facilitation of increased cooperation with the intelligence community” (Donley and Schwartz 2011, 17). As the Executive Agent for Space, the Secretary of the Air Force ultimately oversees all space programs, approves the launch rates to enable space-based capabilities, and ensures space-based capabilities are delivered for DoD users on time and within budget. In light of the strategic direction previously discussed, the DoD is pursuing options to specifically promote international agreements and partnership in space. This includes usage and cost-sharing of communication systems and improving space situational awareness. Starting with FY12, the DoD is also pursuing a new acquisition strategy for space-related systems.

The new strategy of Evolutionary Acquisition for Space Efficiency involves procuring block buys of satellites, fixed price contracting, stable research and development investment, and tailored annual funding (Donley and Schwartz 2011, 16). This approach hopes to relieve the government of increased unit costs due to production

line breaks or inefficient labor, place risk back on the commercial vendor, and aid in stabilizing research and development funding. In addition to this new strategy, the DoD is also looking to stabilize and ultimately reduce funding for spacelift. Over the years, the DoD has consistently failed to deliver satellites for launch for a number of reasons. As a result, launch costs have been erratic and created inefficiencies in launch scheduling. The USAF conducted three studies over the past two years and all three concluded that "immediate commitment to a fixed annual production rate for launch vehicles is imperative to sustain the industrial base and control costs" (Donley and Schwartz 2011, 16). In consideration of the current strategic focus and the challenges the US will face in the coming years, there is a tremendous opportunity to evaluate the overarching US space enterprise (to include NASA's 2011 efforts to generate a new Space Launch System program from the canceled Constellation program). Unfortunately, such an undertaking is beyond the scope of this study. This study will only focus on DoD spacelift requirements and if they can be achieved in a more efficient approach without reducing the success rates and launch production rates attained under the current EELV program.

Definitions

The following is a short list of key terms and definitions pertinent to this study. These terms come from Joint and USAF publications. These definitions provide an understanding of the key concepts associated with the general spacelift discussion.

Assured Access: Our capabilities to gain access and operate in the space domain. This includes launch and range operations, satellite control networks, as well as terrestrial communication networks that link ground nodes of our command and control systems (Moseley 2006, 32).

Constellation: A number of like satellites that are part of a system. Satellites in a constellation generally have a similar orbit. For example, the GPS constellation consists of 24 satellites distributed in six orbital planes with similar eccentricities, altitudes, and inclinations (Chairman of the Joint Chiefs of Staff 2009, GL-6).

Space Asset: Any individual part of a space system as follows. (1) Equipment that is or can be place in space (e.g., a satellite or a launch vehicle). (2) Terrestrially-based equipment that directly supports space activity (e.g., satellite ground station) (Chairman of the Joint Chiefs of Staff 2009, GL-8-GL-9).

Space Weather: The conditions and phenomena in space and specifically in the near-Earth environment that may affect space assets or space operations. Space weather may impact spacecraft and ground-based systems. Space weather is influenced by phenomena such as solar flare activity, ionospheric variability, energetic particle events, and geophysical events (Chairman of the Joint Chiefs of Staff 2009, GL-10).

Spacelift: Ability to deliver satellites, payloads, and material into space. Spacelift operations are conducted to deploy, sustain, augment, or reconstitute satellite constellations supporting US military operations and/or national security objectives (Chairman of the Joint Chiefs of Staff 2009, II-3).

Primary and Secondary Research Questions

In order to thoroughly evaluate and determine if reducing DoD spacelift cost is feasible and make credible recommendations, the author has generated several research questions. The primary research question is can DoD spacelift requirements be achieved in a more efficient approach without reducing the success rates or launch production rates

realized under the current EELV program? This question will be evaluated by three secondary questions. These questions are:

1. What is the status of the current US spacelift industrial base? What rocket engine manufacturers remain in the US?

2. What are the current costs for DoD spacelift services? What are the costs for spacelift conducted by others (i.e. internationally, commercially, or across US government agencies)?

3. What are the current and anticipated launch rates and trends? What are the reliability rates for spacelift? What factors does DoD consider for EELV reliability and the philosophy of EELV mission assurance?

Scope, Limitations and Delimitations

This study determines if the DoD can conduct spacelift in a manner that is more efficient or through an approach that reduces time, resources, and complexity while maintaining the current program manufacturing and launch performance effectiveness. There are several important limitations affecting the study's scope. The first limitation is this paper will not address any classified material, proprietary information, or information determined to be "For Official Use Only" in order to permit unlimited distribution. Secondly, this study will not evaluate specific tactics, techniques, and procedures relating to spacelift range operations. Additionally, the author will not identify inadequacies or shortcomings regarding current launch vehicle or support system capabilities. The author will primarily evaluate US-based commercial launch service providers but will also consider international launch service providers in this study. Foreign state-run launch capabilities will not be considered. In considering the launch service providers in this

study, only those providers that can launch payloads between 8,500 to 20,000 lbs to GTO will be considered for comparison. This is the typical weight range for most DoD and commercial payloads launched with EELVs. Additionally, this is supported by the EELV Operational Requirements Document (AFSPC 002-93-11) that states EELV performance at a minimum must be capable of launching payloads weighing: 17,000 lbs to LEO; 8,500 to GTO; 41,000 lbs to Polar Orbit; and 13,500 lbs to Geostationary Earth Orbit (Space and Missile Center 2010, 3). Finally, this study will not evaluate range activities or costs associated with range support as these are separate activities and costs that would be required regardless of launch vehicle. Only readily available launch data, cost data, or relevant policies and instructions will be included and used within this study.

Assumptions

Three assumptions impact this research. The first assumption rests with the current state of the EELV program. Although the FY12 budget remains under review (as of 30 September 2011), the proposed EELV budget and proposed acquisition strategy are the baseline aspects of the EELV program used in this study. Secondly, the author assumes no additional policy changes or modified national security guidance will be generated to contradict the current applicable United Nation's space treaties, US Space Transportation Policy, or US Space Policy. Finally, the author assumes EELV program launches (regardless of potential launch service provider) will continue to launch only from Vandenberg AFB, California and Cape Canaveral AFS, Florida. This would negate any additional costs associated with establishing new or additional range infrastructure, specific vehicle launch site construction, or launch support contracts as may be required to launch from existing or planned spaceports (such as Spaceport America in New

Mexico, Mojave Air and Space Port in California, or Kodiak Launch Complex in Alaska) or other test ranges (such as NASA's Wallops Flight Facility in Wallops Island, Virginia or the US Army's White Sands Missile Range in New Mexico).

Significance of Thesis

The DoD has had over 80 consecutive, successful launches since 1999 and the *FY12 US Air Force Posture Statement* maintains that "spacelift is a critical component of the national security space enterprise" (Donley and Schwartz 2011, 16). Although, the DoD has been successful over the past decade, spacelift remains an extremely complex and unforgiving business. The limited number of commercial entities and space-faring nations that exist support this point. Additionally, launch failures continue to occur worldwide. From 1 January 2009 to 30 September 2011, there have been 14 launch failures out of 208 launches worldwide (Kyle 2011). Although the failure rate based on these trends is only approximately 5.8 percent, each failure included multimillion dollar payloads. One example was the $424 million Glory spacecraft NASA lost with the Orbital Sciences Corporation's Taurus XL launch mishap on 4 March 2011 (Hennigan 2011a) (Beneski 2011).

Recent launch failures by commercial space launch providers and other international space-faring nations demonstrate the tremendously intricate nature of spacelift. As the DoD Executive Agent for Space, the USAF is responsible for procuring and launching all national security assets into orbit. The following chapters describe the materials available to support this thesis, the methodology applied to evaluate the proposed research questions, the study results, and derived conclusions. This study reviews DoD's spacelift doctrine, defines DoD's mission assurance philosophy, explores

other commercial launch service alternatives, evaluates recent launch trends, reveals anticipated launch forecasts, conducts a confirmatory study on a similar thesis, and provides recommendations on whether or not the DoD can conduct spacelift in a manner that is more efficient or through an approach that reduces time, resources, and complexity while maintaining the current program manufacturing and launch performance effectiveness.

CHAPTER 2

LITERATURE REVIEW

This study seeks to determine if launch service options can achieve a more efficient approach without reducing the success rates or launch production rates realized under the current EELV program. A tremendous amount of literature is available on the subject of spacelift and rocketry. US government policies, DoD doctrine, USAF doctrine, Federal Aviation Administration (FAA) reports, congressional testimony, news and journal articles, online resources, and other historical reports or briefings inform this study. There was more than sufficient material on the subject and although there have been past studies regarding DoD spacelift, this study focuses on current open source information and trends. The previous chapter established the background and the aims for this spacelift study. To properly assess and identify efficient approaches for DoD spacelift, this chapter presents the literature evaluated based on areas of: historical significance; current policies and doctrine; and data associated with trends and launch vehicles.

Historical Literature

The historical perspective describes the importance of space-based capabilities, the critical role spacelift plays in the high frontier of space, the history of DoD spacelift, and the history of the EELV program. Chapter 1 summarized the preponderance of this perspective and provided the necessary background regarding the environment in which the DoD is operating with the EELV program.

A variety of sources were reviewed on the topic of space-based capabilities. Several online sources demonstrated the importance of space-based capabilities and illustrated existing space threats. These included online news sources such as MSNBC, DoD news releases, DefenseNews.com, Federal Times, *Los Angeles Times*, and other online outlets. Additionally, the recent *National Security Space Strategy* provided historical data relating to the congestion in space and the numbers of nations operating in space.

Regarding the critical role spacelift provides and the historical review of DoD spacelift, numerous policy documents and other online resources were reviewed. The George C. Marshall Institute web site contained several copies of presidential decisions and National Security Council documents pertinent to this study. These documents aided in describing how the DoD approached spacelift and eventually established the EELV program. As noted in chapter 1, these documents illustrate DoD reliance on the STS program during the early 1980s, the transition to expendable launch vehicles in the late 1980s, the establishment of a DoD spacelift program separate from the STS, the establishment of DoD spacelift as the primary means of spacelift for all government missions, and the new focus to invigorate the commercial market.

The EELV program history provided understanding of the current program and established a line of departure from which to identify efficiencies. Two articles from the *Program Manager* journal provided the primary means for this review. The articles in *Program Manager* focused on how the Space Launch Modernization Plan review led to the EELV program. It also shed light on the aims of the program and the requirements the EELV program must achieve. Aside from this article, the Congressional Research

Service and Government Accountability Office also provided historical details on the EELV program. They provide an independent assessment of EELV program health and summarized relevant issues encountered with the program. The ULA and Federal Trade Commission web sites also provided historical perspective concerning the merger of the two original EELV launch service providers under a 50-50 joint venture in order to help reduce launch costs. As part of EELV program history, the author also encountered a Naval Postgraduate School thesis that focused on DoD's assured access to space. Major David Ehrlich completed his thesis in December 2010. It is closely aligned to the aims of this study, and provides a basis for comparison.

Ehrlich's thesis evaluated whether the DoD could afford to continue and maintain the current EELV strategy for assuring access to space when other more efficient foreign options could be used (Ehrlich 2010, 3). He approached this dilemma by examining the current US space policies, comparing applicable foreign spacelift systems (specifically Arianespace *Société Anonyme*, Japan's Aerospace Exploration Agency, and Sea Launch *Aktiengesellschaft*), and identifying contributing factors that affect DoD's spacelift approach and US space policies. Ehrlich argued that the DoD can improve upon its spacelift strategy by striving either to establish foreign spacelift partnerships or by taking steps to diversify and expand the US commercial spacelift market (Ehrlich 2010, 76-79). Although Ehrlich based his conclusions on several recent US space policies, several additional DoD strategic policies have since been established. These new policies enhance direction provided in the *National Space Policy* and support Ehrlich's conclusions as they relate to space-based systems. One discrepancy encountered with his thesis lies with his argument that the DoD subsidizes spacelift in order to maintain

assured access to space while other cheaper foreign commercial spacelift options are available. As discussed later in this study, nations subsidizing launch services are prevalent in the spacelift industry. This includes Arianespace *Société Anonyme* (Arianespace SA) and Japan's Aerospace Exploration Agency that Ehrlich evaluated. Additionally, Ehrlich used several cost factors incorrectly and he failed to portray costs accurately. Some of the costs were intended to demonstrate cost growth for the EELV program but in reality they depict the cost growth for all space systems. This deviation will be discussed and clarified later as part of this study. In regard to DoD's approach to spacelift, Ehrlich failed to describe the DoD's philosophy of mission assurance oversight. This philosophy requires the EELV provider to thoroughly demonstrate a reliable, fully tested launch vehicle prepared for launch (to include integrated system evaluations, subsystem testing, fabrication data, test validation data, and individual component reviews). As a result, costs within the EELV program cannot be accurately compared to costs associated with other commercial vendors due to the significant number of man-hours and products required in order to demonstrate the EELV launch vehicles are flight worthy for DoD standards. Because Ehrlich's thesis is closely aligned with this study, it will be used as a basis for comparison in order to either confirm or discount his findings. In addition to the historical literature that provided understanding and perspective, this study also evaluates current US space policies and DoD doctrine.

Current Policies and Doctrine

The current US government policies and doctrine provided the context and established criteria for DoD involvement with spacelift. The US government policies used includes Title 10 of the US Code, *National Space Policy, National Defense Strategy,*

National Intelligence Strategy, National Security Space Strategy, National Military Strategy, and the *Chairman of the Joint Chiefs Guidance for 2011.* These guiding policies and strategies all reiterate the significance of space as a global commons, recognize the challenges faced in today's joint environment to include threats to our space-based capabilities, and the importance of spacelift to enable space-based capabilities. The *National Space Policy* reiterates past guidance stating "US government payloads shall be launched on vehicles manufactured in the US unless exempted" (The White House 2010b, 5). Although this policy directs use of vehicles manufactured in the US, it also includes direction for international cooperation by promoting appropriate cost- and risk-sharing partnerships and to augment US capabilities by leveraging the capabilities of our allies and space partners (The White House 2010b, 6-7). The *National Space Policy* provided specific direction to: work jointly across the government in obtaining reliable, responsive, and cost-effective spacelift; to enhance efficiency, increase capacity, and reduce launch costs through spacelift infrastructure modernization; and to develop spacelift required to assure and sustain reliable and efficient access to space when US commercial capabilities or services do not exist (The White House 2010b, 5).

The *National Security Space Strategy* furthers the direction included in the *National Space Policy* but particularly through guidance to establish international coalitions and strategic partnerships. As stated in the *National Security Space Strategy,* "[b]y sharing or exchanging capabilities, data, services, personnel, operations, and technology, we can ensure access to information and services from a more diverse set of systems-an advantage in a contested space environment" (Gates and Clapper 2011, 8).

Joint and USAF doctrine provided context for DoD involvement with spacelift. The *Capstone Concept for Joint Operations* and *The Joint Operating Environment* describe the need to safeguard the global commons and highlight the importance of the space domain for military operations. Joint Publication 3-14 (JP 3-14) and Air Force Doctrine Document 2-2 are the capstone doctrine publications that describe space operations for the DoD and USAF. They establish the fundamentals for space operations, describe how military forces command and control space forces, and plan and execute space operations. They differ in that the joint doctrine also details the four space mission areas and how they support the full spectrum of military operations. JP 3-14 formally delineates spacelift operations as a component of the Space Support Mission Area (Chairman of the Joint Chiefs of Staff 2009, II-3).

Air Force Doctrine Document 2-2 focuses more on the command and control of space forces, planning, and execution of space operations. It differs from JP 3-14 by discussing the importance of developing space professionals that "can articulate how space operations integrate into, contribute to, and improve military operations" (Moseley 2006, 38). Regarding spacelift, these doctrine publications agree that spacelift presents unique challenges that requires extensive planning and are closely tied to civil and commercial capabilities. At the operational and tactical level, Air Force Instruction (AFI) 10-1211, AFI 21-202 Volume 3, Air Force Space Command Instruction (AFSPCI) 10-1208, and AFSPCI 21-202 Volume 2 are additional guidance documents that dictate specific roles and responsibilities regarding how DoD spacelift operations occur across the USAF and specifically within AFSPC. These instructions provide insight on the required activities and the specific AFSPC processes designed to support the overarching

doctrine previously discussed. Beyond doctrine, the final element of literature used includes reports relating to DoD budgets, launch trends, and detailed information regarding comparable launch vehicle capabilities.

Budgets, Trends and Launch Vehicle Literature

The US Government Accountability Office, Center for Strategic and Budgetary Assessments, and the Center for Strategic and International Studies provided independent assessments on costs, spacelift capabilities, and industrial capacity. These independent organizations all emphasize the need to maintain a strong space-related industrial base. Space is critically important to US interests and the US must remain a global leader in space. Since the US space-related industrial base is largely dependent on the DoD and US national security, maintaining this industrial base is a key challenge. In general, all three organizations also agree that the overall financial health for top-tier manufacturers is good but there is a cause for concern for second- and third-tier manufacturers. In addition to the data provided by these independent sources, cost information was also gathered from the USAF Financial Management and Comptroller web site, the Office of the Secretary of Defense presentations provided during the DoD Cost Analysis Symposium in February 2011, and directly from some of the launch service providers considered in this study. The USAF Financial Management and Comptroller web site provided insight into the FY01 and FY12 budgets while the Office of the Secretary of Defense provided a current review of DoD space acquisitions and particularly the EELV program. Regarding spacelift services, the costs differ significantly between launch vendors and will be discussed as part of the methodology and analysis for comparison. As noted in the literature, the approach used by each vendor to develop their technology, the amount of

time required to establish their respective capability, and their specific approach to perform launch operations contribute to the cost differences.

Online resources provided space launch trend data and past launch performance statistics. These sources included Ed Kyle's *Space Launch Report* web site and the *Spaceflight Now* web site. Of particular importance, a 22 December 2009 letter distributed to members of the US Congress by the President's Office of Science and Technology Policy commented on the capacity of the US industrial base to develop and produce rocket engines to meet US government and commercial spacelift needs (Holdren 2009, 1). This letter also specifically highlighted historical trend data regarding launches performed around the world (data generated by Science and Technology Policy Institute tasked by the President's Office of Science and Technology Policy as a Federally Funded Research and Development Center). These data points provide context on the historical launch rates and the amount of launches performed around the world. This particular letter also highlighted how the US industrial base provides a diverse range of capabilities and can more than adequately provide for the identified spacelift needs of the US government and commercial sector. With new launch service providers like Space Exploration Technologies Corporation (SpaceX) entering into the US launch market, the potential exists to help rejuvenate US rocket propulsion development.

In reviewing this data, ULA's Atlas V and Delta IV performance has been supported through approximately 50 years of launch experience, over 15 launches for each launch vehicle design (27 for the Atlas V and 17 for the Delta IV as of 30 September 2011), and well over 200 launches performed by associated heritage launch vehicles (Kyle 2011). SpaceX is considered unproven in the launch business. They have

been in the market for less than a decade, attempted less than 10 launches so far, experienced numerous failures as part of their development, but they are attracting a lot of attention and commercial business as a result of their progress and low-cost potential. Regardless of limited experience and development issues, SpaceX is still a viable contender as a new entrant to the space launch market.

Another source used throughout the research was the FAA's *2011 US Commercial Space Transportation Developments and Concepts.* This document provided information that coincided with data obtained directly from launch vendor web sites like ULA and SpaceX. It also provided insight into other US-led launch options that exist to include Orbital Sciences Corporation's small launch vehicles like the Taurus II and Minotaur IV. It also included information regarding Sea Launch *Aktiengesellschaft* (Sea Launch AG) that launches the Zenit-3SL from a mobile sea launch platform, typically from the Pacific Ocean. Aside from existing launch vehicles, this reference also provided insight into current launch vehicle development efforts. Although it validated and provided significant data to support this study, it also highlighted the limited number of vendors available in the US to meet DoD's launch requirements previously identified in chapter 1. In addition to the *2011 US Commercial Space Transportation Developments and Concepts*, this study also evaluated and used the FAA's *Commercial Space Transportation: 2010 Year in Review*, the FAA's *2011 Commercial Space Transportation Forecasts*, and Spacesecurity.org's *Space Security 2011*. These documents elaborate on worldwide trend data associated with the commercial spacelift market over the past year. They also provided anticipated global demand for commercial spacelift services from 2011 through 2020. Spacesecurity.org's *Space Security 2011* also

reconfirmed the historical perspective on spacelift, EELV program support, and global details on 2009 developments regarding space-related capabilities. Based on the extensive literature evaluated with this study topic, the significance of this study remains to fill the void in identifying efficient approaches for DoD spacelift.

Significance of Thesis in Relation to Existing Literature

In evaluating available literature, little addressed approaches to improve spacelift efficiency. Although Ehrlich's thesis provided two recommendations to improve on DoD spacelift efficiency, his findings failed to identify root causes for high costs within the EELV program or ways to gain efficiencies under the current program. The most evolutionary change to DoD spacelift over the years has been the transition to procure launch services rather than procuring launch vehicles. Regardless, this study remains significant and aims to fill that gap by providing other options to modify the DoD's spacelift approach. Additionally, this study did not use proprietary data to compare and evaluate various spacelift options. All data was obtained strictly through open sources and what was readily available in the media.

CHAPTER 3

RESEARCH METHODOLOGY

This study examines if DoD spacelift requirements could be achieved in a more efficient approach without reducing the success rates or launch production rates realized under the current EELV program. The previous chapter focused on the various types of literature used to evaluate this thesis. This chapter establishes how the author answered the research questions. In evaluating the primary and secondary research questions, the author required a thorough comparison across applicable launch service vendors, an examination of US spacelift rocket engine industrial base, and an evaluation of performance characteristics associated with vendor launch vehicles. In addition to answering the associated research questions, this study also conducted a confirmatory evaluation of Ehrlich's findings. This chapter specifically addresses the research design, how the data was collected, how the various spacelift options were compared, and the strengths and weaknesses encountered with this methodology.

Research Design

This study assessed DoD spacelift by answering the research questions associated with this study and by thoroughly evaluating and comparing Ehrlich's thesis. To determine if DoD spacelift can be performed more efficiently, the secondary research questions were evaluated in two ways. The initial portion of the research was a descriptive study based on documentation review. This review provided an understanding of the current US spacelift industrial base, identified rocket engine manufacturers remaining in the US, identified costs for spacelift services that were made available to the

public, determined reliability rates for various vendors, identified DoD EELV reliability standards, identified the DoD approach to oversee EELV processing and launch operations through the philosophy of mission assurance, and examined the historical and anticipated launch trends. This documentation review addressed the preponderance of the secondary research questions in order to gain an improved understanding of the US spacelift industrial base, to identify the standards and approach the DoD has taken with EELV and DoD spacelift, and to provide an understanding of past launch trends and the anticipated launch market.

In addition to the descriptive study, the author also conducted a comparison study. This identified and evaluated similarities and differences between six commercial spacelift vendors that could launch payloads between 8,500-20,000 lbs to GTO. Each vendor was evaluated based on capabilities, costs, and historical reliability. The vendors included ULA (current EELV program launch service provider), SpaceX, Orbital Sciences Corporation, and the international commercial entities of Arianespace SA, Sea Launch AG, and ILS. These findings aided in understanding the other spacelift services currently available, how they compare to the current EELV program, and identify if alternatives to the current EELV providers exist. The final component of this research was a confirmatory study. This required the use of existing material on the topic in order to validate the research findings. In order to enable this research design, extensive research material was required.

Information Collection

Information on the topic of spacelift was readily available although proprietary information and specific aspects of vendor data were difficult to obtain, unavailable, or

not used. Two data collection means supported this study. The internet provided the preponderance of information. The bulk of the historical and doctrine oriented material used in this study was obtained from US government agency web sites, vendor web sites, research institutions, and online news stories. This included historical data, doctrine and policy documents, cost data, vendor capabilities, and operational trend data. In addition to the internet, the author also researched through the Combined Arms Research Library at Fort Leavenworth, Kansas and Air University Library at Maxwell AFB, Alabama. Through these institutions, the author evaluated past studies pertaining to the EELV program and DoD spacelift. The author was also able to locate another recent thesis on the subject. Collectively, in using the internet and library resources, the author obtained enough material to conduct a descriptive study, initiate a vendor comparison, and conduct a confirmatory study.

Comparison Criteria

A vendor comparison is essential for this study in order to identify and evaluate similarities and differences between six commercial spacelift vendors based on specific criteria. The criteria used includes the current EELV program operational requirements, cost data (as determined through open source), and country of manufacturing origin.

The criteria focused primarily on performance and historical information associated with the six commercial spacelift vendors. These vendors were chosen because they are commercial spacelift vendors currently in the market and are capable of launching payloads between 8,500-20,000 lbs to GTO. Government controlled space agencies such as NASA, Japan’s Aerospace Exploration Agency, Indian Space Research Organization, Russian Federal Space Agency, National Space Agency of Ukraine, or the

China National Space Administration are not within the scope of this study. They are state run organizations and not commercial vendors. The comparison criteria used for each vendor include published costs, launch vehicle performance characteristics, and launch vehicle reliability. The results helped assess how commercial launch service providers compare to ULA, the current EELV program provider.

Confirmatory Study

Major David Ehrlich's thesis also sought to determine if the DoD could continue to afford and maintain its current spacelift strategy (Ehrlich 2010, 3). His exhaustive research on national policies, commercial spacelift vendor capabilities, and other contributing factors, provided two specific findings. Ehrlich recommended that the DoD establish international cooperation partnerships "with America's economic and military allies to create a more robust and resilient space launch capability" (Ehrlich 2010, 77). His second finding was that "the time was ripe to modernize regulations and policies" in order for the DoD to implement "a strategy that is potentially not only more effective, but efficient as well" (Ehrlich 2010, 79). Ehrlich's findings, offer an opportunity to validate or corroborate this study's conclusions.

Strengths and Weaknesses of Methodology

The plethora of information readily available on the subject of spacelift and the EELV program was a key strength. Spacelift has been around for over 50 years. Technological advancements, national policies, proliferation of technology, and mankind's fascination with space have resulted in volumes of material. This material provided additional perspective on the subject beyond first-hand EELV program

experience. The material supported a thorough descriptive study on the subject, a straightforward comparison of commercial spacelift options, and even supported a confirmatory study to corroborate the research findings.

The study's limited scope and the nature of the research information limited the overall assessment. The scope of the study limited the research to open source material such as online resources, periodicals, unclassified reports, doctrine, and policies. Proprietary information and For Official Use Only sources were not used. This limited the accuracy and scope of the project. Despite the limitations, the amount of information available on the overall topic of spacelift was quite extensive.

The primary issue with this amount of material was the accuracy and applicability to the research questions. Although plenty of material was available regarding the EELV program, for vendor comparison and anticipated launch trends, the multitude of sources did not necessarily coincide. Vendor cost data varied significantly over time and could not be equally compared. Launch methodology and business approaches between all vendors was also difficult to identify and compare. Additionally, the field of space launch is a dynamic and ongoing global activity that is affected by global markets, material costs, technology advancement, and political influences. An example of this dynamic environment may be demonstrated by attempting to define where space begins. In recent years, the DoD has removed the definition from JP 3-15. It is actually an arbitrary location resulting from the dynamic nature of Earth's atmosphere and near-Earth space. Although unofficial, it is widely accepted that space begins around 100 km or 62 miles above sea-level (Shostak 2004). As a result of the varying data and diverse information encountered with this study, some recommendations and conclusions may not coincide

with all the sources pertaining to the subject matter. This is due to current source data or because of better understanding regarding spacelift activities than previous authors.

CHAPTER 4

ANALYSIS

Can DoD spacelift requirements be achieved in a more efficient approach without reducing the success rates or launch production rates realized under the current EELV program? Previous chapters focused on the aims for this spacelift study, the history of DoD spacelift, the available and relevant literature, and the methodology applied to answer the various research questions associated with this study. This chapter provides the analysis results from documentation reviews, the comparison study of six spacelift vendors, and the confirmatory study based upon Ehrlich’s thesis.

The first section of this chapter describes the current DoD spacelift standards associated with the EELV program, the DoD philosophy of mission assurance, and provides a current review of DoD’s acquisition for spacelift services under the EELV program. The next section analyzes the domestic industrial base for launch vehicle vendors and rocket engine manufacturers. Following the industrial base review, the next section describes the historical launch trends and anticipated launch rates. The final section of this chapter is a confirmatory study on Ehrlich’s findings. Altogether, this chapter describes the results in answering the secondary research questions, it also establishes the foundation to determine whether or not DoD spacelift requirements can be achieved in a more efficient approach without reducing the success rates or launch production rates realized under the current EELV program.

DoD Assured Access to Space

As directed in section 2273 of Title 10 US Code, the DoD is responsible for sustaining the availability of at least two space launch vehicles capable of launching national security payloads and a robust space launch infrastructure and industrial base (Office of the Law Revision Counsel, US House of Representatives 2011). JP 3-14 and Air Force Doctrine Document 2-2 are the capstone doctrine publications describing space operations. JP 3-14 formally delineates spacelift operations as a component of the Space Support Mission Area (Chairman of the Joint Chiefs of Staff 2009, II-3). Air Force Doctrine Document 2-2 focuses more on the command and control of space forces, planning, and execution of space operations. Regarding spacelift, these doctrine publications agree that spacelift presents unique challenges requiring extensive planning that are closely tied to civil and commercial capabilities. At the operational and tactical levels, AFI 10-1211, AFI 21-202 Volume 3, AFSPCI 10-1208 and AFSPCI 21-202 Volume 2 are the guiding documents that dictate specific roles and responsibilities regarding how DoD spacelift operations occur across the USAF and specifically within AFSPC. These instructions provide insight on the required activities and the specific AFSPC processes designed to support spacelift operations. Of particular note, DoD's unique management process is referred to as mission assurance.

Due to a series of launch failures in the late 1990s, the USAF conducted a Broad Area Review to thoroughly examine the failures and identify corrective actions. This review found mission assurance processes were lacking because acquisition reforms from the early 1990s lessoned rigorous oversight requirements in an effort to reduce costs. The review suggested incorporating clear accountability, strengthening systems engineering

discipline, adding independent reviews, and employing government mission assurance (Pawlikowski 2008, 6). Unlike terrestrial systems that may be taken out of the field to be modified, tested, and redeployed, space systems are limited to a single opportunity for deployment. As depicted in figure 5, launch is often the greatest risk to any space system over its entire lifecycle. Because of the Broad Area Review recommendations, mission assurance has become a mandatory process and cornerstone philosophy that aids the DoD in ensuring successful launches.

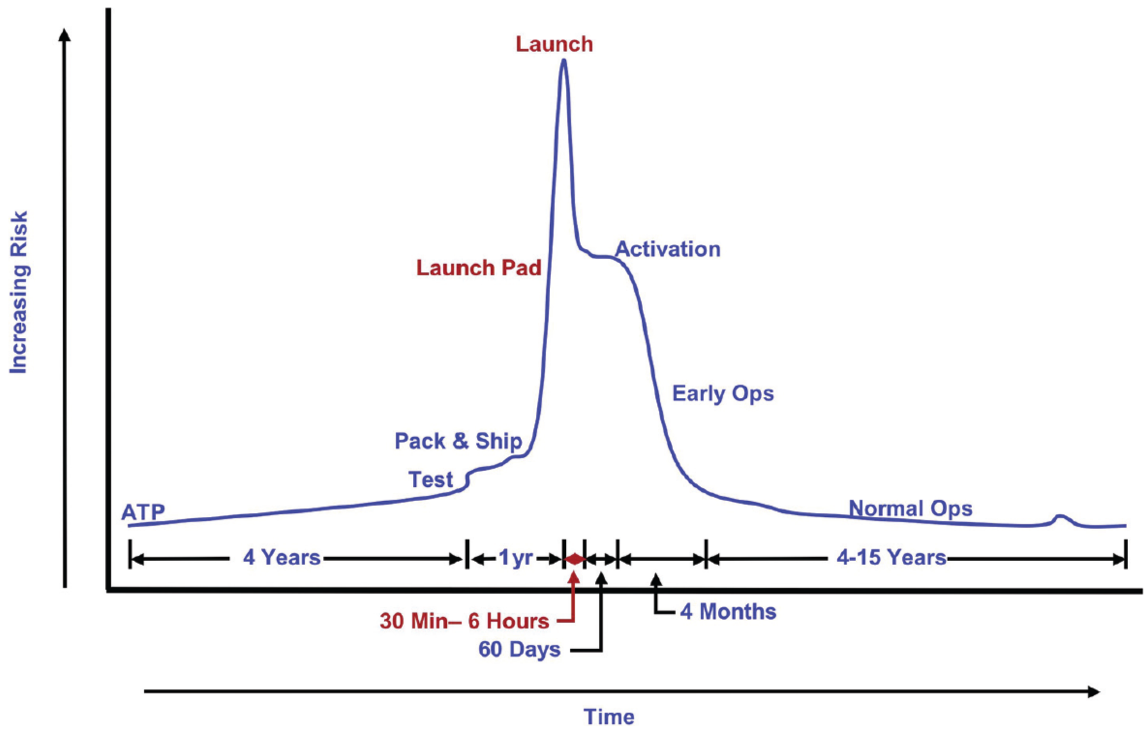


Figure 5. Notional Risk as a Function of System Lifecycle
Source: Major General Ellen M. Pawlikowski, USAF, “Mission Assurance-A Key part of Space Vehicle Launch,” *High Frontier* (August 2008): 6.

As Major General Ellen Pawlikowski stated in her *High Frontier* article, “each launch offers one and only one chance at mission success . . . there are no second chances for success” (Pawlikowski 2008, 6). It is for these reasons the DoD has pursued a rigorous process and culture to ensure spacelift is successful. In broad terms, mission assurance is a combination of system design assurance, operational mission assurance, and independent mission assurance (Pawlikowski 2008, 7).

System design assurance and operational mission assurance are closely related. They involve in-depth review and validation of system design, manufacturing, launch site operational processing, systems integration, and flight and ground systems operational test and evaluation. These assurances lead to launch readiness verification and design certification (Pawlikowski 2008, 7). The independent mission assurance ensures a third technical review and assessment, independent from the launch service provider and government program office team. Altogether, this process provides a structured and disciplined approach to ensure launch success. It also drives the culture for spacelift that demands “strict attention to detail, rigorous analysis of issues, and a commitment to 100 percent mission success” (Pawlikowski 2008, 7). This is a different approach than most other systems and capabilities the DoD acquires. Most terrestrial systems and information technology capabilities follow the standard DoD acquisition processes that involve research and development, rigorous development test, operational testing with users and in the operational environment, and follow-on testing for any modifications or upgrades that occur after the system is fielded. Terrestrial systems and capabilities can be readily tested and modified, especially after fielded in the operational forces. The DoD does not currently have capabilities to conduct hardware modifications or significant

modernization upgrades once space systems are placed in orbit. Additionally, spacelift is the only means to enable a space system to achieve orbit. Unlike aircraft, such as a C-17 with personnel and operational payloads that are capable of take-off yet have opportunities to land in the event of an issue in flight, current DoD spacelift does not have the capability to safely jettison or "land" to safeguard a payload in the event of an issue in flight. This generates the mission assurance requirement for extensive scrutiny and oversight to ensure the space system is prepared for launch, ground systems are prepared to operate the space asset, launch vehicle is flight worthy and launch ready, and launch and range systems are fully tested and prepared for launch. Because of the technical and performance benefits potentially realized through mission assurance, the USAF instituted specific direction in several publications. According to AFI 21-202 Volume 3, mission assurance is defined as a:

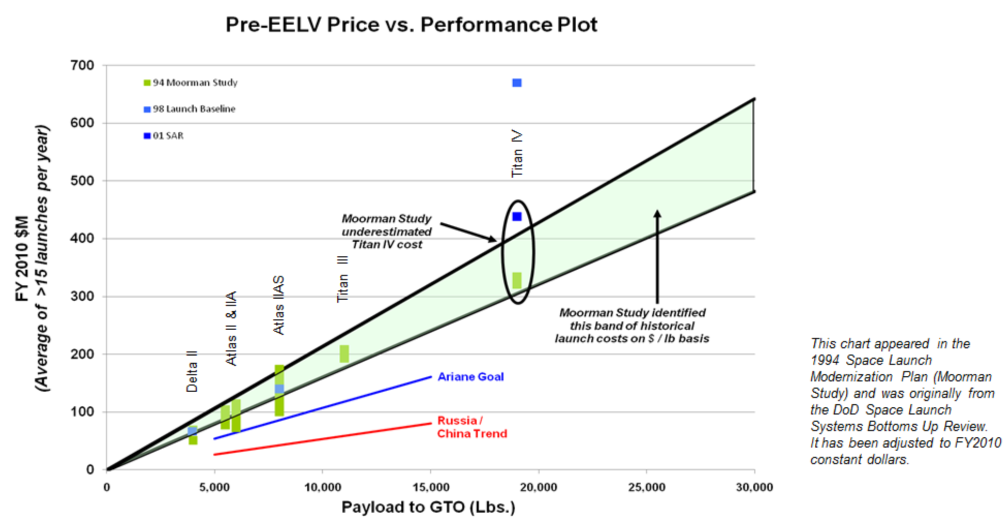
> technical and management process rigorously, continuously, and iteratively employed over the life-cycle of a launch system (mission conception to space vehicle separation) to maximize mission success. Mission assurance encompasses system engineering, risk management, quality assurance, and program management by an experienced, stable launch agency team. Mission assurance is achieved through integrated development processes and/or independent technical assessment and requires expenditures commensurate with criticality of the mission and the consequences of failure. (Headquarters, United States Air Force 2009, 3: 5)

This process is involved at every echelon of the DoD launch team and occurs on both the launch vehicle and the space vehicle. Per AFSPCI 10-1208, the Commander, AFSPC is the individual with overall responsibility for spacelift mission assurance (Headquarters, Air Force Space Command 2011, 6). Portions of mission assurance may be delegated to the Commander, 14th Air Force such as responsibilities for public safety, range operations, and base operating elements of mission assurance. 14th Air Force, in

turn, typically delegates these responsibilities to the launching space wing commanders. The Commander, AFSPC is also responsible for flight worthiness certification and this is usually delegated to the Commander, Space and Missile Center (depending on the type of DoD mission supported, other organizations at lower levels may perform the flight worthiness certification). Flight worthiness certification “ensures the launch agency has confidence that the launch vehicle, spacecraft, and launch agency ground system risks have been resolved, or are known and deemed acceptable” (Headquarters, Air Force Space Command 2011, 4). From the technicians and the engineers that perform technical observation and conduct risk assessments (including approximately 50 military and government civilians in a space launch squadron) to the launch groups, space wings, 14th Air Force, Space and Missile Center, and AFSPC, every aspect of the DoD oversight process involves spacelift mission assurance. The largest drawback with spacelift mission assurance is the additional time required for processing and launch preparation compared to other commercial launch operations that don’t employ a similar philosophy. Moreover, mission assurance also reduces opportunities for efficiency in processing and launch preparations as a result of required and continuous DoD involvement and oversight. In addition to the operational aspects of DoD launch oversight, the acquisition management of the EELV program has also changed since the program started.

In the requirements generation process of the late 1990s, the EELV acquisition strategy aimed to leverage the commercial market because government business was anticipated to be a minority in the launch business. Figure 6 highlights the heritage launch costs the DoD evaluated as part of the 1994 Space Launch Modernization Plan and as part of the EELV requirements generation process. This highlighted the higher

ratio of cost per lbs delivered to orbit compared to other international providers. For instance, Ariane aimed to launch a 6,000 lbs payload to GTO at nearly $70 million while the historical Atlas II launched the same payload for up to $120 million (cost data based on FY10 dollars) (Khol 2011, 3). The results from the 1994 Space Launch Modernization Plan eventually aided in driving an EELV requirement to reduce recurring launch costs 25 to 50 percent compared to heritage systems depicted on figure 6 (Space and Missile Center 2010, 3).



- ***1980-1994 : NSS averaged 8 launches per year + Non-NSS averaged 7.5 per year***
- ***1994 SLMP: recommends a single provider based on a modular (common core) family of vehicles as the most cost effective and reliable alternative to meeting the nation's expendable launch vehicle requirements***
- ***Dec 1996: EELV program Milestone I decision***
- ***Nov 1997: USD(A&T) approved new acquisition strategy to allow two providers to enter EMD / Initial Launch Services phase & to maintain competition throughout life of program based on a revised forecast of a significant increase in launch demand from commercial satellite providers***

Figure 6. 1994 Moorman Study to EELV
Source: Curt Khol, "EELV Program Background Cost Perspective" (Briefing, DoD Cost Analysis Symposium 2011, Washington, DC, 17 February 2011), 3.

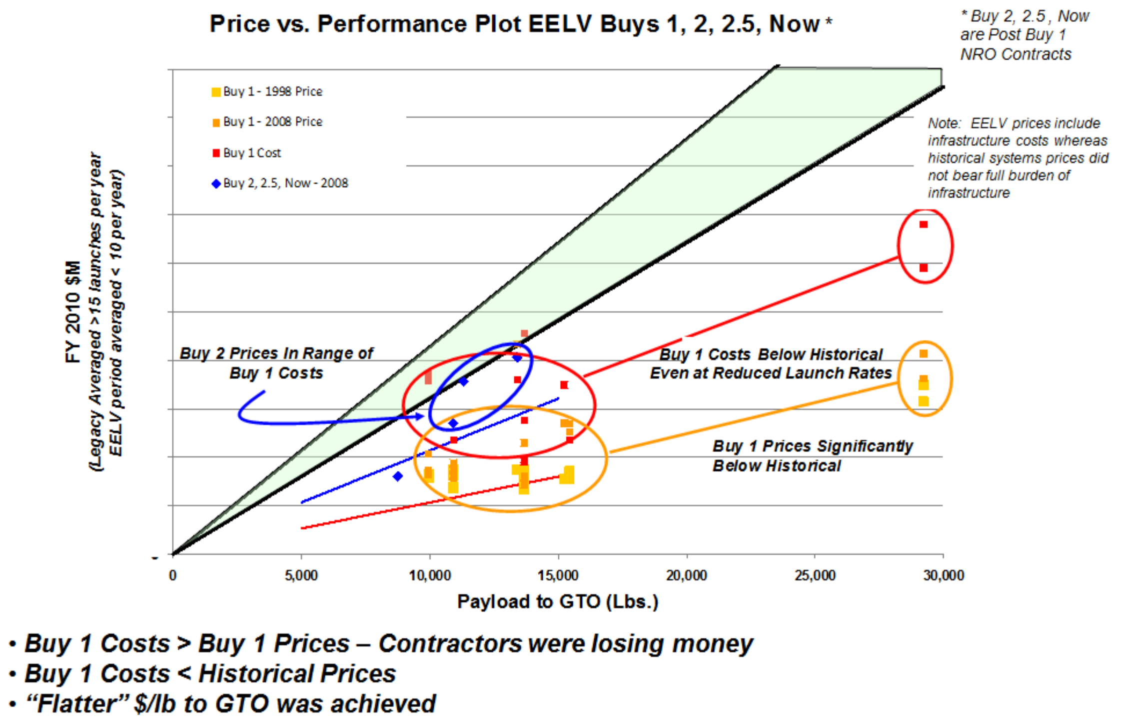


Figure 7. EELV Realized Business
Source: Curt Khol, "EELV Program Background Cost Perspective" (Briefing, DoD Cost Analysis Symposium 2011, Washington, DC, 17 February 2011), 6.

The initial EELV strategy aimed to promote competition and encourage contractor investment in vehicle development. The anticipated commercial market failed to materialize and the US government became Boeing's and Lockheed Martin's primary customer. To compound the situation, only 21 of the 28 original 1998 DoD contracted launches occurred within ten years (Khol 2011, 5). Figure 7 compares the incremental historical procurement costs from the initial contract (known as "Buy 1") to the current realized procurement. It particularly exhibits the EELV program's increasing costs and the true price the DoD pays to maintain assured access to space. Using the example of an 11,000 lbs payload, the price for a 1998 EELV "Buy 1" launch was around $125 million (based on FY10 dollars) (Khol 2011, 6). By 2008, the EELV "Buy 1" launch price rose to

nearly $200 million and actually ended up costing nearly $230 million per launch (Khol 2011, 6). The most recent negotiated EELV launch prices (known as “Buy 2, 2.5, Now”) have risen to nearly $270 million per launch (Khol 2011, 6). As this example demonstrated, the EELV launch costs have steadily increased over the past decade and it is becoming as expensive as historical launch vehicles.

Since the merger of both launch vendors into ULA, the DoD has sought additional cost savings. This includes contracting for EELV services. The DoD established two contracting mechanisms with ULA (Butler 2011). One contract is the EELV Launch Capabilities contract that covers infrastructure and technical services. This contract is a cost-plus contract that requires the government to pay the vendor for service expenses identified and determined by the vendor. These costs are meant to primarily pay the vendor for technical services rendered. The other contract with ULA is the EELV Launch Services contract that covers the costs for launch vehicles. This contract is a fixed-price contract that the DoD and ULA negotiate based on unit costs for launch vehicles. In late 2010, the USAF (led by David Van Buren, USAF Service Acquisition Executive) started a thorough review of these contracts and the overall program cost structure (Butler 2011). Through the initial course of this review, it was determined that the DoD needs to look more closely into the overhead and indirect costs within the EELV program. Because of the way the contracts are currently structured, Erin Conaton (Undersecretary of the Air Force) concluded “I do not think we have a very good understanding of the cost” (Butler 2011). As a part of this review, the Office of the Secretary of Defense, Cost Analysis and Program Evaluation office determined that the current EELV program is facing increasing costs approaching heritage launch vehicle cost trends. This is can be

investigated in figure 8 by evaluating the cost for a 14,000 lbs payload to GTO where an Atlas V may cost nearly $250 million and a Delta IV may cost over $300 million per launch (Khol 2011, 8). Historical launch vehicles would launch the same payload between $220-300 million per launch (Khol 2011, 8). It is important to note that even though launch costs have risen over time, they also include the cost for launch infrastructure which was not included in the heritage launch vehicle program costs (Khol 2011, 8). Additionally, the Delta IV costs have also been greatly affected by dramatic increases in prices for rocket engines (such as the RS-68) (Khol 2011, 8). To address the overall EELV cost increases and in parallel to this study, the USAF is also working to modify the acquisition strategy for several space programs as part of the FY12 budget process.

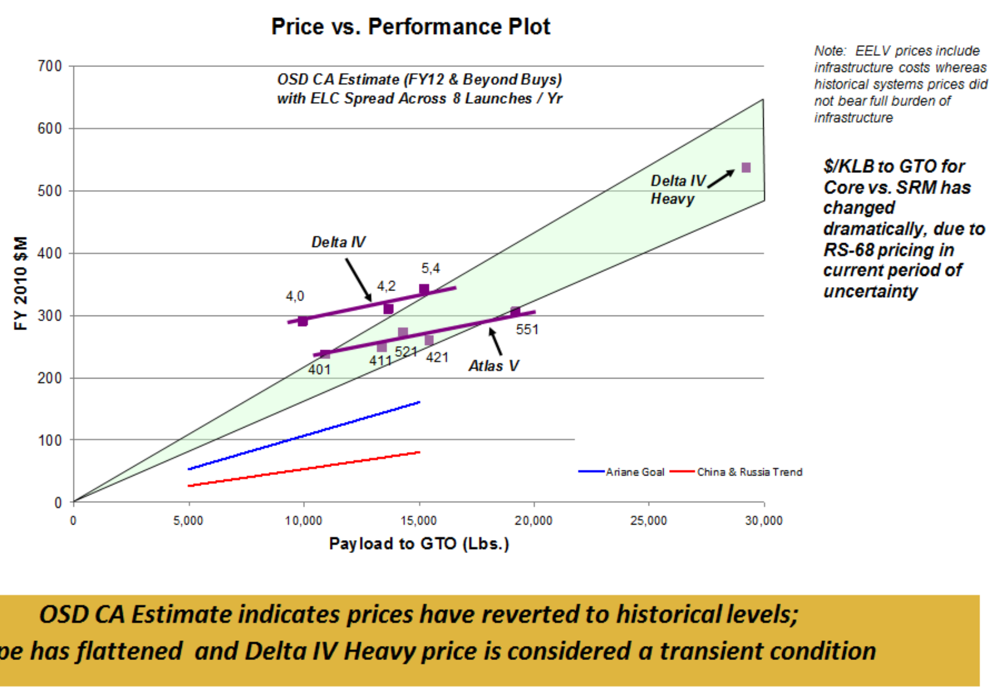


Figure 8. OSD Cost Assessment
Source: Curt Khol, "EELV Program Background Cost Perspective" (Briefing, DoD Cost Analysis Symposium 2011, Washington DC, 17 February 2011), 8.

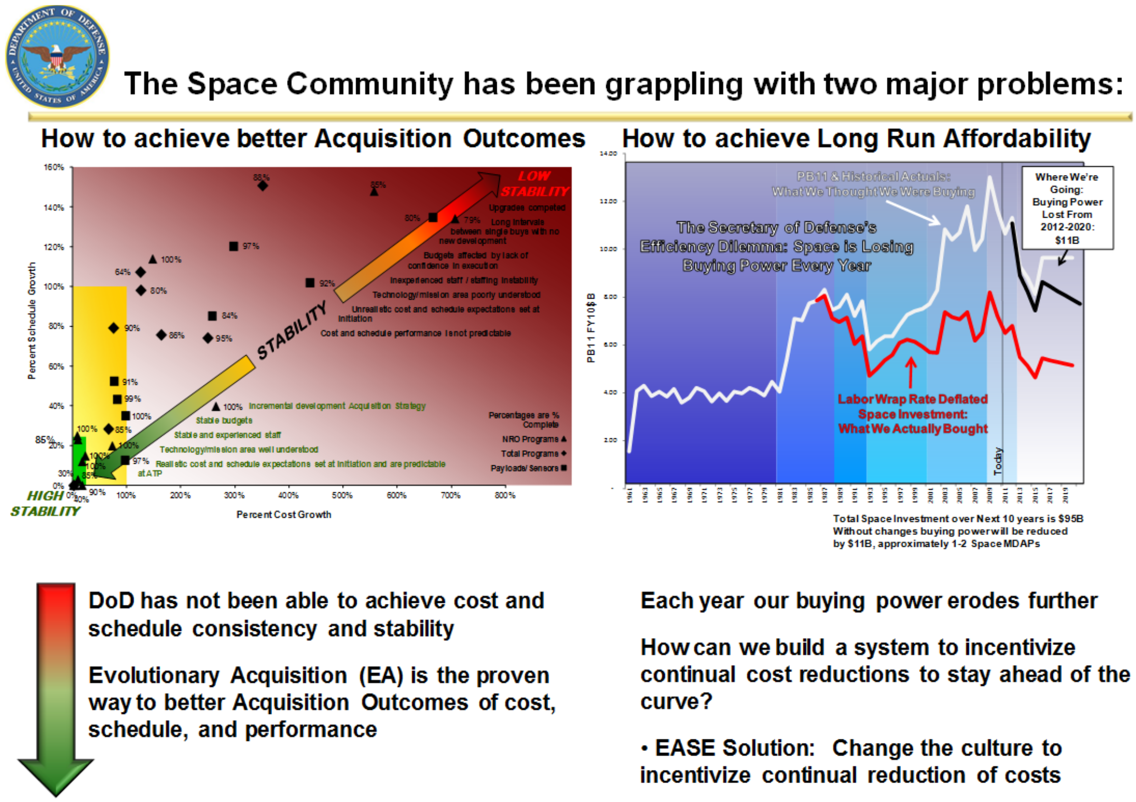


Figure 9. Space Community Challenges

Source: Bess Dopkeen and Jon Sweet, "Evolutionary Acquisition for Space Efficiency" (Briefing, DoD Cost Analysis Symposium 2011, Washington DC, 17 February 2011), 14.

The USAF is pursuing a revised procurement approach for space systems. This approach is called Evolutionary Acquisition for Space Efficiency and supports two particular satellite programs. These are the Advanced Extremely High Frequency satellite program and the Spaced-Based Infrared System satellite program for FY13 (Brinton 2011). This new strategy attempts to reestablish acquisition excellence and to drive savings within a fiscally constrained environment. As shown in figure 9, the DoD is seeking ways to improve upon past space systems acquisition outcomes and attain long-run affordability (Dopkeen and Sweet 2011, 14). The USAF is looking to the

Evolutionary Acquisition for Space Efficiency strategy as a means to improve upon past shortcomings.

Under this new strategy, the USAF is aiming to procure space systems using block-buys with fixed-prices and authorized multiyear procurement. As highlighted in figure 9, this is an enduring effort to lower costs, provide consistency in annual procurement, and aid in stabilizing the industrial base from historical inefficiencies and erratic costs. This is only available for mature, proven programs that have completed research, development, test, evaluation, and initial procurements. As of 1 July 2011, the House and Senate Armed Services Committees agreed to the FY12 strategy for the Advanced Extremely High Frequency satellite program but were unwilling to authorize specific appropriations beyond FY12. On the other hand, the House Appropriations Committee wanted additional details regarding the strategy as it felt the advance appropriations were nothing more than a budgetary gimmick (Brinton 2011). Although it appears Congress is unsupportive of this latest strategy, the DoD remains committed to block-buys and procuring space system end-items differently.

Similar to this new strategy, the USAF is also looking to modify the EELV program procurement by establishing a stable annual procurement of launch vehicles without matching them to specific spacecraft until later in the spacecraft production cycle. Starting with FY12, the USAF is seeking five annual launches under the EELV program (four for AF missions and one for the Navy) (Harrison 2011, 52). This includes one heavy launch (involving three booster cores) and four medium launch vehicles (each launch potentially augmented between 0-5 solid rocket motors depending on the flight profile required for the payload). This strategy aims to provide flexibility in planning the

launch manifest if satellite production schedules slip while also providing ULA and their launch vehicle component manufacturer's assurance and commitment to stable procurement rates (Butler 2011). Like the Evolutionary Acquisition for Space Efficiency, this strategy hopes to stabilize the industrial base while procuring launch services through a committed block-buy approach. To counter the latest EELV acquisition approach, the US Government Accountability Office conducted a study between September 2010 and September 2011 that generating seven recommendations for the Secretary of Defense to consider. This latest report highlighted concerns that the DoD was failing to make fully informed decisions prior to instituting a new EELV acquisition strategy that could lead to a surplus of unused launch vehicles (Chaplain 2011, 9-10).

This latest report highlighted the growing concern with DoD spacelift and the EELV program. Based on recommendations made by AFSPC and the National Reconnaissance Office in March 2011, the Secretary of the Air Force created a new executive position to spearhead efforts in developing a new EELV acquisition strategy and to become the new executive administrator for all DoD spacelift (including the EELV program). This new position removed executive oversight of DoD spacelift from the Program Executive Officer for Space and created the Program Executive Officer for Space Launch (Chaplain 2011, 1). Although this shift in executive oversight enables focused leadership and evaluation, the Government Accountability Office emphasized the DoD still lacks insight into true costs, industrial health, and impacts of mission assurance. As a result of their analysis, the Government Accountability Office concluded that the DoD must "ensure it is taking the time it needs to collect and assess sufficient information on which to base its new acquisition strategy" (Chaplain 2011, 23). The

specific recommendations the report provided for the Secretary of Defense include: conducting an independent health assessment of the domestic launch industrial base (particularly the engine manufacturers); reassessing the latest annual EELV block buy approach; gaining understanding with NASA's heavy-lift launch program to facilitate improved negotiations to maximize government investment; refraining from waivers for Federal Acquisition Regulation requirements regarding contractor certified costs and pricing data; ensuring launch mission assurance activities are sufficient and not excessive while also finding ways to incentivize EELV launch providers to implement efficiencies; examining opportunities to improve spacelift coordination among all government agencies; and finally developing a science and technology plan to improve and evolve launch technologies (Chaplain 2011, 24). The DoD responded by concurring with six of the seven recommendations and partially concurred with the recommendation to reassess the EELV block buy approach (Chaplain 2011, 29). Regarding this approach, the DoD is already collecting refined contractual information and supporting documentation to appropriately develop a new EELV acquisition strategy that balances launch prices, operational requirements, budgetary realities, and the possibility of new entrant competition (Chaplain 2011, 29). The DoD responded to this report by stressing that six of the seven recommendations were already in-work with aims of supporting the new acquisition strategy. The DoD also stressed that some may take considerable time to develop or evolve (Chaplain 2011, 29-31). Although this Government Accountability Office report highlighted a number of concerns for the DoD, this report also recognized the vital need of government investment in DoD spacelift and the critical capabilities required to place national space-based assets into orbit. Based on the established

requirements associated with DoD spacelift, an understanding of the DoD philosophy in overseeing commercial launch services, and an analysis of the current EELV acquisition program, a review of the spacelift industrial base is required in order to continue to answer the secondary research questions.

Spacelift Industrial Base

The EELV Operational Requirements Document (AFSPC 002-93-11) established three primary requirements. First, launch vendors would provide launch vehicles capable of launching payloads weighing: 17,000 lbs to LEO; 8,500 to GTO; 41,000 lbs to Polar Orbit; and 13,500 lbs to Geostationary Earth Orbit. Second, the launch vehicles would demonstrate between 97 and 97.5 percent reliability depending on the configuration. The final key requirement was to reduce recurring cost of launch by 25 to 50 percent compared to the heritage launch vehicles the government used during the 1990s, such as the Atlas II and Titan families of launch vehicles (Space and Missile Center 2010, 3). Based on these requirements and the need to strictly use commercial service providers, the author identified six spacelift vendors to compare and evaluate in this study.

The vendors evaluated include ULA (current EELV program launch service provider), Space Exploration Technologies Corporation (SpaceX), Orbital Sciences Corporation, and three international commercial entities including Arianespace *Société Anonyme* (SA), Sea Launch *Aktiengesellschaft* (AG), and International Launch Services Incorporated (ILS). These vendors were primarily selected based upon advertised capabilities to meet the weight to orbit launch requirements and commercial availability. Although reliability and costs are also key drivers under the EELV program requirements, these were found to be imperfect and deficient. Reliability rates are

ultimately dependent on the rate of launch in a business where launches are limited and expensive. True DoD costs of using other launch service providers is unknown based upon the potential increase cost to conduct launch services in parallel with DoD launch oversight, mission assurance validation, and approval. Proven reliability rates for most of the reviewed launch vehicles are based on very few launches (less than 30) and are not truly indicative of the launch vehicle capability.

Additionally, historical launch costs are not typically readily available to the public. This is presumed to be the business practice launch vendors use to safeguard negotiated launch costs from other customers (each customer develops unique launch requirements and some may establish multiple launch contracts to reduce costs) and from launch service rivals. As a result, the author used speculated data provided from various sources to provide insight of a rough order of magnitude for a range of potential launch service costs. To identify and evaluate similarities and differences between the six commercial spacelift vendors, an open source analysis was conducted based on being capable of launching payloads between 8,500-20,000 lbs to geosynchronous orbit. Each vendor was evaluated based on capabilities, costs, and historical reliability information.

United Launch Alliance

Within ULA, two families of vehicles were evaluated to establish the performance baseline the other launch service providers must match. The first is the Atlas V launch vehicle family. According to the *ULA Atlas V Product Card*, the Atlas V is a modular two-stage launch vehicle that provides flexibility, reliability, and capability centered on a common booster core (United Launch Alliance 2010a). It may be configured with up to five additional solid rocket boosters, a customer configured upper stage booster, and

various sized payload fairings in order to meet a variety of customer performance requirements. These options enable the Atlas V to launch up to 40,800 lbs to Low Earth Orbit (LEO at an altitude of 400 km with an inclination of 28.5 degrees) and 19,260 lbs to Geosynchronous Transfer Orbit (GTO is an elliptical orbit of 35,786 X 185 km and at an inclination of 27 degrees) (United Launch Alliance 2010a). Although an Atlas V Heavy Lift Vehicle is mentioned in the *ULA Atlas V Product Card* with baseline performance capabilities, it has never been demonstrated. This variant depends on three common booster cores compared to a single common booster core used to date. The Atlas V launch vehicle is based on over 50 years of heritage experience and incremental modern improvements. It debuted in 2002 and has successfully launched 26 payloads in 27 launch attempts at a reliability rate of 96 percent (as of 30 September 2011) (Kyle 2011). The one imperfection in its performance record is a partial failure where the payload was not delivered to its intended orbit due to an inflight performance anomaly (Ray 2007). The payload would eventually achieve an operational orbit under its own power and the launch was deemed a success although this caused reduced on-orbit life for the spacecraft because of propellant used to achieve an operational orbit. The Atlas V common booster core engine is based on a Russian manufactured RD-180 (produced by *RD-AMROSS*, 50-50 joint venture between Pratt and Whitney Rocketdyne and *NPO Energomash*) and the Centaur upper-stage is based on a US manufactured RL-10 (produced by Pratt and Whitney Rocketdyne). Solid rocket boosters used on the Atlas V (between zero to five boosters depending on mission need) are produced in the US by Aerojet.

In addition to the Atlas V, ULA also provides the Delta IV as a proven launch vehicle family. It is also based on over 50 years of heritage experience combined with design simplicity, manufacturing efficiency, and streamlined integration to satisfy all mission requirements (United Launch Alliance 2010b). Like the Atlas V, the Delta IV launch vehicle family is also based on its own common booster core applying proven heritage components with efficient launch site processing and integration, configurable options with up to four graphite epoxy motors and two payload fairings sizes. This modular approach enables the Delta IV two-stage launch vehicle to launch payloads up to 29,450 lbs to LEO and 15,470 lbs to GTO (United Launch Alliance 2010b). ULA has also used a Delta IV Heavy version that is capable of launching payloads of to 49,740 lbs to LEO and 28,620 lbs to GTO (United Launch Alliance 2010b). This version is based on using three of the Delta IV common booster cores. The Delta IV first launched in 2002 and has successfully launched 12 payloads in 12 launch attempts, maintaining a reliability rate of 100 percent (Kyle 2011).

The Delta IV Heavy has launched 4 payloads in 5 launch attempts with a reliability rate of 80 percent (Kyle 2011). The one failure is considered a partial failure as it also failed to deliver the mass simulator payload to the intended orbit. This occurred on the demonstration flight and did not impact any commercial or government payloads. The Delta IV common booster cores are based on US manufactured RS-68 engines (produced by Pratt and Whitney Rocketdyne) and the upper-stage is based on a US manufactured RL-10 engine that is slightly different than the Atlas V RL-10 (also produced by Pratt and Whitney Rocketdyne). The strap-on graphite epoxy motors used on the Delta IV are

produced in the US by Alliant Techsystems. The Delta IV is capable of using zero, two, or four graphite epoxy motors depending on the mission need.

Because of the configurable capabilities of the Atlas V and Delta IV and ULA's dependence on suppliers for critical launch vehicle components, costs can vary significantly. Upon review and limited interpretation of the proposed FY12 DoD Budget Request in conjunction with comparison statements made by SpaceX (Space Exploration Technologies Corp. 2011a), the generic cost for an Atlas V and Delta IV is estimated to be around $180 million for each launch. Additionally, the cost for a Delta IV Heavy is around $350 million per launch. Regarding country of origin, ULA is a 50-50 joint venture owned by Lockheed Martin Corporation and The Boeing Company, each based in the US. Although individual components of each launch vehicle may originate outside the US (such as the RD-180 rocket engine for the Atlas V) the launch vehicles are assembled and integrated domestically. Based on the domestically available launch service providers, SpaceX is also a viable alternative to ULA.

Space Exploration Technologies Corporation

SpaceX, a US based company established in 2002 and headquartered in Hawthorne, California, offers the Falcon 9 launch vehicle. According to SpaceX, the Falcon 9 is based on design and experience of the Falcon 1 (smaller launch vehicle) with advances in reliability, cost, flight environment, and time to launch (Space Exploration Technologies Corp. 2011b). It is designed for maximum reliability through nine engines clustered together in the first stage and triple redundant flight computers and inertial navigation supported with GPS for payload insertion accuracy (Space Exploration Technologies Corp. 2011b). The Falcon 1 is not considered for this evaluation due to the

limited lift capability. It is important to note that SpaceX demonstrated manufacturing, processing, integration, and launch operations through the initial Falcon 1 flights for use with Falcon 9 and follow-on launch systems. The Falcon 1 launch vehicle experienced 3 failures out of 5 launches (Kyle 2011); with the most recent Falcon 1 launch conducted in July 2009 with the successful delivery of the RazakSAT Earth observation satellite (Shanklin 2011). The three failures occurred from SpaceX's launch site in the Kwajalein Atoll and involved two demonstration flights (validating system design and performance) and one test mission flight involving an experimental DoD payload and two NASA cube satellites (Space Exploration Technologies Corp. 2011d). Since the initial failures, SpaceX has successfully demonstrated their launch services and particularly the capabilities of the SpaceX designed booster-stage Merlin engine and the SpaceX designed upper-stage Kestrel engine. Both of these engines are designed and manufactured within SpaceX and are the basis for the Falcon 9 (as illustrated in figure 10 with the 8 December 2010 Falcon 9 launch from Cape Canaveral AFS) and Falcon Heavy launch vehicles.

The Falcon 9 two-stage launch vehicle is capable of launching payloads up to 23,050 lbs to LEO and up to 10,000 lbs to GTO (Space Exploration Technologies Corp. 2011b). SpaceX has demonstrated 100 percent reliability for the Falcon 9 based on two demonstration flights conducted from Cape Canaveral AFS, Florida (Kyle 2011). Both occurred in 2010 and were launched as part of a proof of concept and as a demonstration for the NASA Commercial Orbital Transportation Services program (Space Exploration Technologies Corp. 2011d). SpaceX is advertising the cost for a Falcon 9 launch between $54 and $59.5 million (Space Exploration Technologies Corp. 2011b).

Figure 10. Falcon 9 Launch
Source: Space Exploration Technologies Corporation, “SpaceX’s Dragon spacecraft successfully re-enters from orbit,” Photo by Chris Thompson, 8 December 2010, http://www.spacex.com/updates.php#Update121510 (accessed 30 September 2011).

The Falcon Heavy launch vehicle is designed on three Falcon 9 booster cores with a unique cross-feed propellant capability between the boosters (Space Exploration Technologies Corp. 2011c). Like the Falcon 9, there is a standard payload fairing but customized fairings are available if required. According to SpaceX, it is capable of launching up to 117,000 lbs to LEO and up to 42,000 lbs to GTO (Space Exploration Technologies Corp. 2011c). The Falcon Heavy has not been demonstrated but SpaceX currently anticipates conducting a demonstration launch in 2012 from its launch site currently under construction at Vandenberg AFB, California (Space Exploration Technologies Corp. 2011c). SpaceX advertises the cost for a Falcon Heavy launch

between $80 and $125 million (Space Exploration Technologies Corp. 2011c). In addition to ULA and SpaceX, the only other US launch service provider evaluated in this study is Orbital Sciences Corporation.

Orbital Sciences Corporation

Orbital Sciences Corporation, a US based company that started in 1982 and is headquartered in Dulles, Virginia, provides launch services based on several different launch vehicles. Based upon the payload evaluation criteria and the various launch vehicles Orbital Sciences Corporation offers, none of their current launch vehicles are capable of meeting the EELV criteria. Regardless, Orbital Sciences Corporation is currently developing the Taurus II launch vehicle that is capable of launching payloads very near to the payload mass criteria used in this evaluation.

As Orbital Sciences Corporation mentioned on their web site, the Taurus II (depicted in figure 11) is a two-stage launch vehicle that expands the capabilities of the current Taurus XL and is designed for responsive, cost-effective, and reliable launch for medium-class payloads (Orbital Sciences Corp. 2010). Like ULA's approach, the Taurus II is designed on flight-proven subsystems shared by other Orbital Sciences Corporation launch vehicles to include the Pegasus, heritage Taurus, and Minotaur launch vehicles. The Taurus II is capable of launching payloads up to 14,330 lbs to LEO and 3,300 lbs to GTO (Orbital Sciences Corp. 2010). It remains under development and Orbital Sciences Corporation anticipates an initial demonstration flight before the end of 2011 from its launch complex on Wallops Island, Virginia (also advertised compatibility to launch from Vandenberg AFB, California, Kodiak Launch Complex, Alaska, and Cape Canaveral AFS, Florida) (Orbital Sciences Corp. 2010).

Figure 11. Taurus II Concept
Source: Orbital Sciences Corporation, "Taurus II," 2011, http://www.orbital.com/SpaceLaunch/TaurusII (accessed 30 September 2011).

Although partially based on the heritage Taurus launch vehicle, the Taurus XL launch vehicle successfully launched 6 payloads out of 9 launches with a demonstrated reliability of 67 percent (Kyle 2011). The two most recent launches failed due to issues associated with payload fairing separation (Beneski 2011). The most recent failure occurred in March 2011 where NASA's $424 million Glory scientific satellite failed to achieve orbit and was destroyed (Hennigan 2011a) (Beneski 2011). The first-stage booster is based on using two US-manufactured AJ26-62 engines produced by Aerojet (domestic commercial derivative of the Russian NK-33 engine) (Orbital Sciences Corp. 2010). Orbital Sciences Corporation will use the Russian NK-33 engines (36 engines

already delivered to the US with another 36 available in Russia) until it is necessary to have Aerojet produce the AJ26-62 engines (C. Clark 2010). The upper-stage is powered by a US-manufactured CASTOR 30A solid motor produced by Alliant Techsystems (Orbital Sciences Corp. 2010). Because the Taurus II has not been demonstrated, the cost for a launch is not readily known and difficult to speculate. According to David Steffy in 2008, the projected cost for a Taurus II launch is approximately $65 million (Steffy 2008). As Orbital Sciences Corporation commented in September 2010, the Taurus II aims to provide launch for less than $100 million a launch compared to the estimated $250 million for each EELV launch (C. Clark 2010). Aside from ULA, SpaceX, and Orbital Sciences Corporation, the remaining commercial launch service providers evaluated are predominately foreign-owned companies.

Arianespace *Société Anonyme*

Arianespace SA is a European-based company that has provided commercial and foreign government launch services since 1980 (Arianespace SA 2011a). The primary launch vehicles in use by Arianespace SA include the Ariane 5, Soyuz, and Vega. Launch operations are conducted from South America at Europe’s Spaceport in Kourou, French Guiana (approximately 500 km north of the equator). Of the three current launch vehicles available through Arianespace SA, only the Ariane 5 currently meets the payload launch criteria. The Soyuz launch vehicle will also be evaluated with this review as its capabilities are very near the capabilities required under the EELV program. Like the ULA launch vehicles, the Ariane 5 is also based upon heritage Ariane vehicles. Arianespace SA considers the Ariane 5 a heavy-lift launcher as a result of its unique approach for spacelift. The Ariane 5 primarily launches and deploys two satellites to orbit

for each launch (referred to as dual-manifest capability). This creates cost sharing for each launch and helps lower individual customer launch costs.

Figure 12. Ariane 5 Launch
Source: Arianespace SA, "Theme: Historic," Photo by Nadia Imbert-Vier, 26 September 2011, http://www.arianespace.com/images/about-us/ads/pdf/2011/09-26%20historic%20 print.pdf (accessed 30 September 2011).

The Ariane 5 launch vehicle is illustrated in figure 12 with the 21 September 2011 launch from Kourou, French Guiana. It primarily consists of a main cryogenic stage booster powered by a European manufactured Vulcain engine. The main cryogenic stage is mated with two solid boosters that aid in first-stage propulsion. The European manufactured HM7B engine powers the upper-stage and can accommodate three different types of payload fairings and a Sylda internal structure if launching two

satellites. These components enable the Ariane 5 to launch up to 42,550 lbs to LEO and 26,450 lbs to GTO (Arianespace SA 2011c). The Ariane 5 launch vehicle has been in service since 1999 and successfully launched and deployed payloads on 56 of 60 launches, equating to 93 percent reliability (Kyle 2011).

With the successful Ariane 5 launch on 21 September 2011 deploying Arabsat-5C and Europe's SES-2, the launch vehicle family extended its current consecutive successes to 46 launches delivering a total of 95 payloads to orbit (Arianespace SA 2011h). The majority of the launch vehicle components are manufactured in nine European countries (Arianespace SA 2011b). Upon component arrival in Kourou, French Guiana, the launch vehicle is assembled, integrated, tested, and verified prior to launch. Arianespace SA does not publicize its price per launch but it is speculated that an Ariane 5 costs around $250 million per launch (Kyle 2006). In addition to the Ariane 5 launch vehicle, Arianespace SA is also preparing to launch with two additional proven launch vehicles, the Vega and the Soyuz.

The Vega launch vehicle is a four-stage launch vehicle designed for small and lightweight payloads (Arianespace SA 2011j). The launch complex for the Vega launch vehicle is under development. Arianespace SA does not expect Vega launch operations to begin until 2012. Primarily due to performance limitations, the Vega launch vehicle is not considered for this study. The Soyuz launch vehicle (similar to 13 July 2001 Soyuz launch depicted in figure 13 from Baikonur Cosmodrome, Kazakhstan) is Arianespace SA's latest launch vehicle offering. Arianespace SA recently completed ground system preparations in Kourou, French Guiana and launched the first Soyuz launch with two European Galileo navigation satellites on 21 October 2011 (Arianespace SA 2011g).

Figure 13. Soyuz Launch
Source: Arianespace SA, "Theme: Delivered," 18 July 2011, http://www.arianespace.com/images/about-us/ads/pdf/2011/07-18-delivered.pdf (accessed 30 September 2011).

The Soyuz is a four-stage launch vehicle based on heritage Soyuz vehicles that have been used for more than 1,700 launches to date (Arianespace SA 2011i). The Arianespace SA version of the Soyuz launch vehicle (Soyuz 2-1b/Fregat) has maintained a reliability rate of 100 percent based on 5 launches to date (Kyle 2011). It can launch payloads in excess of 18,700 lbs to LEO and 6,600 lbs to GTO (Arianespace SA 2011i). The first-stage consists of four boosters around the launch vehicles central core. Each booster is equipped with a Russian manufactured RD-107A engine (produced by *NPO Energomash*). The central core is considered the second-stage booster for the Soyuz. Like the boosters, the central core is also equipped with a Russian manufactured engine, the RD-108A (also produced by *NPO Energomash*). The third-stage booster uses two

different engines dependent on the mission requirements. Either the Russian manufactured RD-0110 (older model engine) or the newer, more powerful RD-0124 (both produced by the Russian *KBKhA* Company). The fourth and final stage is the Russian manufactured Fregat upper-stage (produced by the Russian *NPO Lavochkin*). It is powered by a single main engine that can be restarted up to 20 times in addition to a collection of thrusters for attitude control (Arianespace SA 2011i). This enables the Fregat upper-stage to be autonomous and flexible enough to operate as an orbital vehicle capable of accessing a full range of orbits. Like the Ariane 5 launch vehicle, it is difficult to determine the cost for a Soyuz launch. According to the Space Knowledge Base Blog, a typical Soyuz launch is estimated to be around $40 million per launch (Kyle 2006).

Sea Launch *Aktiengesellschaft*

Sea Launch AG provides heavy-lift launch services through use of the Zenit-3SL launch vehicle. What is unique regarding Sea Launch AG's approach to launch operations is its ocean-based launch platform (a converted North Sea oil drilling platform that is semisubmersible and self-propelled) and an assembly and command ship (known as the Sea Launch Commander) that enables Sea Launch AG to launch directly from the equator (Sea Launch AG 2011d). All other launch service providers launch from land-based spaceports that are typically in the northern hemisphere. Through an equatorial launch, Sea Launch AG is able to take advantage of the additional speed-to-orbit the Earth provides from rotation (Brown 2002). This enables the launch vehicle to either carry additional mass to orbit or require less propellant compared to launching further away from the equator.

In addition to the speed advantage, there is also the ability to launch directly to geostationary orbit without the need of an orbit plane change. This also provides additional fuel savings on the upper-stage booster or payloads while transitioning from a GTO to a geostationary orbit. Through use of an ocean-based launch platform, Sea Launch AG is also able to minimize range costs (through launch in international waters with limited sea or air traffic) and minimizing risk of launching over populated areas.

Sea Launch AG began in the late 1990s. Like the EELV program, Sea Launch AG anticipated a large spacelift demand from the commercial market. It hoped to provide their unique ocean-based launch concept to capture a good portion of the launch demand for geostationary orbit. Originally, The Boeing Company (as majority shareholder with 40 percent stake) led a consortium that owned Sea Launch Limited Liability Company. The remaining shareholders included Rocket and Science Corporation *Energia* (Russian-based company), a Norwegian shipbuilder, and two Ukrainian rocket firms (Hennigan 2011b). Sea Launch Limited Liability Company conducted 30 launches between 1999 and 2009. During this time, they successfully deployed 27 payloads (including the mass simulator used on its demonstration launch in 1999) but also experienced two complete launch failures and a launch anomaly that failed to deliver its payload to its desired orbit even though the payload still managed to achieve orbit (Sea Launch AG 2011b). In addition to its ocean-based launch, Sea Launch Limited Liability Company also supported a land-based launch concept by teaming with a Russian consortium called Space International Services, Limited (Sea Launch AG 2010).

Through this arrangement, Sea Launch Limited Liability Company conducted launches from the Baikonur Space Center (Baikonur Cosmodrome) in Kazakhstan using

the same Zenit-3SL launch vehicle used at sea but with *NPO Lavochkin* payload fairings rather than the Boeing-made fairings used for its ocean-based launches (known as Zenit-3SLB) (Sea Launch AG 2010). Land Launch successfully conducted four launches between 2008 and 2009 (Kyle 2011). Although Land Launch considers all four launches as successes, the initial AMOS-3 communication satellite was deployed short of its desired orbit (Kyle 2011). Most recently, Sea Launch AG successfully launched Intelsat-18 with a Land Launch Zenit-3SLB on 5 October 2011 (Intelsat SA 2011). As a result, the reliability rate for Land Launch Zenit-3SLB is considered 80 percent. According to the Sea Launch web site, no additional launches are planned for Land Launch at this time. Following fall-out from the Sea Launch Limited Liability Company launch failure in 2007, the company began receiving launch cancellations and eventually filed for Chapter 11 bankruptcy protection in 2009 (Hennigan 2011b).

In October 2010, Sea Launch AG emerged from Chapter 11 bankruptcy protection as a result of Rocket and Science Corporation *Energia* investing additional capital and gaining a 95 percent stake in the company (Hennigan 2011b). Sea Launch AG moved its headquarters from Long Beach, California to Bern, Switzerland and restarted ocean-based launch operations with the successful launch and deployment of Atlantic Bird 7 for Eutelsat's digital broadcasting markets on 24 September 2011 (illustrated in figure 14 with the 24 September 2011 launch of the Zenit-3SL) (Sea Launch AG 2011a). With this most recent launch, the overall demonstrated reliability rate for Sea Launch AG Zenit launch vehicles (including the Land Launch missions) is about 89 percent (Kyle 2011).

Figure 14. Zenit-3SL Launch
Source: Sea Launch AG, “Current Mission-Atlantic Bird 7,” 24 September 2011, http://www.sea-launch.com/past_launches/past_atlantic_bird_7.html (accessed 30 September 2011).

The Zenit-3SL is capable of launching payloads up to 30,500 lbs to LEO (Deagle.com 2011) and 13,000 lbs to GTO (Sea Launch AG 2011c). The preponderance of the Zenit-3SL launch vehicle is manufactured in Russia with the exception of the payload fairings which are provided by Boeing. It is considered a three-stage launch vehicle powered by Russian-manufactured engines including the RD-170 for the first-stage booster, RD-120 and RD-8 for the second stage booster, and the 11D58M for the third-stage booster (Deagle.com 2011). Because of the recent changes with Sea Launch AG and their financial issues, the cost for a Zenit-3SL is difficult to estimate. From a historical perspective and for the sake of comparison, the cost for Sea Launch AG services was $70 million per launch in 2006 (Pae 2006).

International Launch Services Incorporated

ILS is a US-based company, founded in 1995 and incorporated in Delaware (International Launch Services Inc. 2011a). It is also a subsidiary of a Russian company, *Khrunicheve* State Research and Production Space Center. ILS emerged from the merger of Lockheed and Martin Marietta companies in 1995 to market Proton launch services (Lockheed and *Khrunicheve-Energia* joint venture launch services) and Atlas launch services (Martin Marietta commercial launch services) (International Launch Services Inc. 2011b). Between 1995 and 2006, ILS conducted commercial launch services using the Proton and Atlas family of launch vehicles, to include eight launches on the Atlas V within the EELV program (International Launch Services Inc. 2011c). In October 2006, Space Transport Incorporated acquired Lockheed Martin's interest in ILS and established ILS as a stand-alone company focused on Proton Breeze M launch services (International Launch Services Inc. 2011b). Through use of the Russian-manufactured Proton Breeze M launch vehicle, ILS launches from the Baikonur Cosmodrome in Kazakhstan (International Launch Services Inc. 2011d).

The ILS Proton Breeze M launch vehicle (seen in figure 15 in transport at Baikonur Cosmodrome, Kazakhstan) is a three-stage booster with a restart able upper-stage that is based on heritage Proton launch vehicles spanning over 45 years and 360 flights (International Launch Services Inc. 2011e). The Proton Breeze M is currently capable of launching payloads up to 47,500 lbs to LEO and 15,600 lbs to GTO (International Launch Services Inc. 2011e). The first-stage booster includes six RD-276 Russian-manufactured engines. The second-stage booster includes one RD-0211and three RD-0210 Russian-manufactured engines. The third-stage booster is powered by one

Russian-manufactured RD-0213 engine. The Breeze M upper-stage is powered by a Russian-manufactured 14D30 gimbaled main engine. ILS started using the Proton Breeze M in 2002 and since then, has used it for 31 launches with the most recent launch occurring on 29 September 2011 with the deployment of QuetzSat-1 commercial communication satellite for *Société Européenne des Satellites Société Anonyme* (SES SA) of Luxembourg (International Launch Services Inc. 2011i).

Figure 15. Proton Breeze M
Source: ILS, "Proton Breeze M brochure," February 2011, http://www.ilslaunch.com/sites/default/files/pdf/ILS%20Proton%20Brochure.pdf (accessed 30 September 2011).

In 2010, ILS started marketing use of the Proton Breeze M as a dual-manifest booster (called Proton Duo) to compete with Arianespace SA's Ariane 5 and depends on a customer's payload requirements and availability (International Launch Services Inc. 2010). This was successfully demonstrated in 15 July 2011 with the ILS Proton Breeze M launch of SES-3 and Kazsat-2 telecommunications satellites (International Launch Services Inc. 2011h). Aside from ILS, the *Khrunicheve* State Research and Production Space Center also uses the Proton Breeze M launch vehicle to support Russian government sponsored missions (19 launches to date). In looking only at the current

Proton Breeze M launch vehicle, the current launch reliability rate is 92 percent based on 46 successful launches out of 50 launch attempts (Kyle 2011). Regarding speculated cost for an ILS Proton Breeze M launch service, it is estimated that each launch costs around $114 million depending on mission specific satellite accommodations (de Selding 2010).

Key Findings from the Industrial Base Review

Table 1. Summary of Launch Vehicle Comparison

Launch Vehicle	Origin	Maximum Lift Capability (lbs)	Launch Location	Reliability (number of launches)	1st-stage Engine	Upper-stage Engine(s)	Costs
Atlas V (EELV)	ULA (US)	LEO: 40.8k GTO: 19.3k	CCAFS & VAFB	96% (26 of 27)	RD-180 (RU)	RL-10A-4-2 (US)	$180M
Delta IV (EELV)	ULA (US)	LEO: 29.5k GTO: 15.5k	CCAFS & VAFB	100% (12 of 12)	RS-68A (US)	RL-10B-2 (US)	$180M
Delta IV Heavy (EELV)	ULA (US)	LEO: 49.7k GTO: 28.6k	CCAFS & VAFB	80% (4 of 5)	Three RS-68As (US)	RL-10B-2 (US)	$350M
Falcon 9	SpaceX (US)	LEO: 23.1k GTO: 10.0k	CCAFS & VAFB	100% (2 of 2)	Merlin (US)	Kestrel (US)	$54-$59.5M
Falcon 9 Heavy	SpaceX (US)	LEO: 117k GTO: 42k	VAFB	Under Development	Three Merlins (US)	Kestrel (US)	$80-$125M
Taurus II	Orbital Sciences Corp. (US)	LEO: 14.3k GTO: 3.3k	Wallops Island, VAFB, Kodiak, & CCAFS	Under Development	NK-33 (RU) or AJ26-62 (US)	CASTOR-30A (US)	$65-$100M
Zenit-3SL	Sea Launch (RU)	LEO: 30.5k GTO: 13.0k	Pacific Ocean on Equator	90% (28 of 31)	RD-170 (RU)	RD-120 (RU), RD-8 (RU), & 11D58M (RU)	$70M
Ariane 5	Arianespace (EU)	LEO: 42.6k GTO: 26.5k	Kourou, French Guiana	93% (56 of 60)	Vulcain (EU)	HM7B (EU)	$250M
Soyoz	Arianespace (EU)	LEO: 18.7k GTO: 6.6k	Kourou, French Guiana	100% (27 of 27 includes 26 RU launches)	Four RD-107As (RU)	RD-108A (RU), RD-0124 (RU), & Fregat (RU)	$40M
Proton Breeze M	ILS (RU)	LEO: 47.5k GTO: 15.6k	Baikonur, Kazakhastan	92% (46 of 50 includes 19 RU launches)	Six RD-276s (RU)	RD-021 (RU), three RD-0210s (RU), RD-0213 (RU), & 14D30 (RU)	$114M

Source: Created by author with data from United Launch Alliance 2010a; United Launch Alliance 2010b; Kyle 2006; Kyle 2011; Space Exploration Technologies Corporation 2011a; Space Exploration Technologies Corporation 2011b; Space Exploration Technologies Corporation 2011c; Orbital Sciences Corporation 2010; C. Clark 2010; Arianespace SA 2011c; Arianespace SA 2011i; Sea Launch AG 2011c; Deagle.com 2011; Pae 2006; International Launch Services Incorporated 2011d; International Launch Services Incorporated 2011e; de Selding 2010.

Cost estimates obtained through various sources for this study are unreliable and depend on a number of variables including the market and component manufacturing (highlighted in table 1). In answering the secondary research question regarding costs associated for launch services, this study identified that costs ranged $40 to $350 million depending on the type of launch capability required. Medium lift payloads could best be accommodated by using the majority of launch vehicles identified at costs varying between $40 and $180 million. The more expensive options demonstrate the higher cost for heavy lift payloads and only three launch vehicles are commercially available at this time (Delta IV Heavy, Falcon 9 Heavy, and Ariane 5). Costs for heavy lift launch services range between $80 and $350 million. In looking at the costs associated with the current EELV launch provider compared to the other launch services, the EELV costs are significantly higher. The primary cost drivers may be associated with the combined mission assurance requirements the US government levied upon ULA. It is assumed that if this requirement is placed on any other launch service provider, costs for vendor launch services would also increase by an undetermined factor and potentially significantly. As a result, this cost data cannot truly be used when determining if DoD spacelift requirements can be achieved cheaper while maintaining its mission assurance philosophy. In addition to cost estimates, another perspective gleaned from this review is an understanding of the domestic industrial base and the rocket engine manufacturers.

The US still maintains a domestic spacelift industrial base. ULA, with over 50 years of heritage experience, and Orbital Sciences Corporation, with over 29 years of heritage experience, possess the most domestic spacelift experience. SpaceX is entering the spacelift market with aims of revamping the launch service provider model by

conducting reliable launch services at lower costs. The launch vehicles used in this evaluation from each of these launch service providers highlight the limited numbers of launches used to calculate success rates. ULA has demonstrated the most launches compared to SpaceX and Orbital Sciences Corporation. Regardless, ULA still has not conducted more than 30 launches for a single launch vehicle family. International commercial launch providers like Arianespace SA, Sea Launch AG, and ILS have accomplished more than 30 launches to date. Between ULA and SpaceX, the reliability rates (excluding the Delta IV Heavy) are currently higher than those performed by Arianespace SA (93 percent), Sea Launch AG (90 percent), and ILS (92 percent). It must be understood that these rates are highly dependent on the number of launches performed but (in ULA's case) may also be attributed to the mission assurance and quality assurance philosophies applied by domestic launch providers.

Regarding rocket engine manufacturers, only one domestic company (Pratt and Whitney Rocketdyne) provides rocket engines for the launch vendors evaluated. The one exception to this finding is SpaceX. It designs and produces its own rocket engines to include the Merlin first-stage engine and Kestrel upper-stage engine. Orbital Sciences Corporation will eventually depend on Aerojet to produce Taurus II main engine but is currently using purchased engines from Russia. In addition to rocket engines, only two domestic manufacturers (Aerojet and Alliant Techsystems) provide solid rocket boosters or motors for the launch vendors evaluated. It appears the majority of rocket engines purchased for commercial launch services are Russian manufactured. When NASA concluding the Space Shuttle program with the final launch on 8 July 2011 (45th Space Wing Public Affairs 2011), the domestic spacelift industrial base became concerned on

the future of launch demand. Pratt and Whitney Rocketdyne commented on 24 September 2011 they were considering selling its Rocketdyne division that produces rocket engines used by current domestic launch vehicles (Harford Business Journal 2011). Other industry members are reducing payrolls by cutting manpower previously used to support the Space Shuttle program. Alliant Techsystems has already cut thousands of jobs in northern Utah that previously supported the development and test of solid-fuel rocket booster motors used by the STS (Oberbeck 2011). These moves stem primarily from the end of NASA's Space Shuttle program, the limited and somewhat erratic number of DoD launches anticipated, and the resulting cost increases for engines manufactured. This is significant for the EELV program because it has become the sole customer based on engines produced for the Atlas V and Delta IV.

This review answered the secondary research question pertaining to the status of the domestic industrial base. By demonstrating the limited options available for domestic launch services and particularly illustrating the health of a small domestic rocket engine manufacturer, there is genuine concern for how closely tied DoD spacelift is to NASA's manned spaceflight approach. Beyond the launch vehicles and launch service providers evaluated, it is equally important to understand current spacelift trends and launch projections to understand the future of launch demand.

Spacelift Trend Analysis

Understanding current worldwide launch trends and projected launch demands aids in providing context regarding the future of the spacelift industry and potential affects to domestic launch service providers. In order to analyze current and anticipated launch trends, a review must specifically evaluate: revenue and launch trends for the

years leading up to 2010; any specific recent events that affect domestic launch services or capabilities; and identify any projected launch trends for the near-term. Using published FAA reports, The White House Office for Science and Technology Policy's 2009 study of the domestic rocket engine industry, the Satellite Industry Association's *State of the Satellite Industry Report*, and Spacesecurity.org's *Space Security 2011*, worldwide trend data was collected to establish the basis for this review.

Revenue and Launch Trends Through 2010

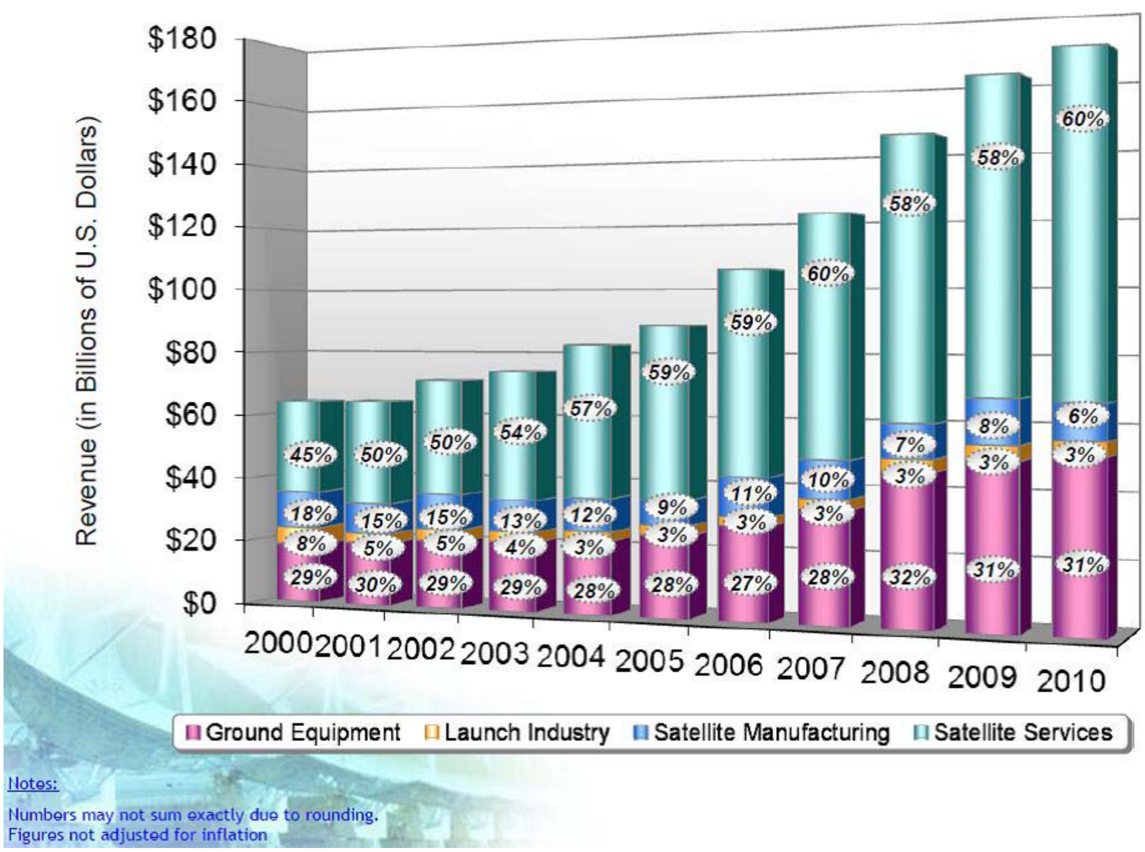


Figure 16. Worldwide Revenues By Segment: Decade in Review
Source: Satellite Industry Association, "World Satellite Industry Revenues by Segment: Decade in Review" (Briefing, State of the Satellite Industry, Washington, DC, June 2011), 12.

On 16 February 2011 Deputy Secretary of Defense, William Lynn, III, observed, "space is far more congested than it was just 20 years ago. It is no longer the private preserve of the US and the then Soviet Union. There are more than 60 nations now that have a presence in space" (Federal News Service 2011, 2). In addition, worldwide commercial space-related revenues reached nearly $170 billion in 2010 (figure 16) (Satellite Industry Association 2011, 12). These sentiments are further echoed in Spacesecurity.org's *Space Security 2011*:

> The commercial space sector has experienced dramatic growth over the past decade, largely as a result of rapidly increasing revenues associated with satellite services provided by companies that own and operate satellites, as well as the ground support centers that control them. This growth has been driven by the fact that space-based services that were once the exclusive purview of governments, such as satellite-based navigation, are now widely available for private customers. In 2010 alone, the world satellite industry had revenues in excess of $168-billion. As well, companies that manufacture satellites and ground equipment have contributed significantly to the growth of the commercial space sector. . . More recently, an energized satellite communication market and launch industry consolidation have resulted in stabilization and an increase in launch pricing. Revenues from 23 commercial launch events in 2010 were close to $2.45-billion, an increase of $43-million over 2009. (Jaramillo 2011, 97)

With increased global involvement in space and particularly spacelift, one can see nearly a three-fold increase in worldwide space systems revenue (figure 16). The most dramatic increase over the past ten years has been the satellite services industry which has seen nearly a 250 percent increase in revenue while the revenues for satellite manufacturing and launch services have remained relatively constant. In studying the US portion of worldwide revenue for two particular space segments that enable space-based capabilities (mainly satellite manufacturing and launch), the status of domestic space services and US leadership in those industries can be better understood.

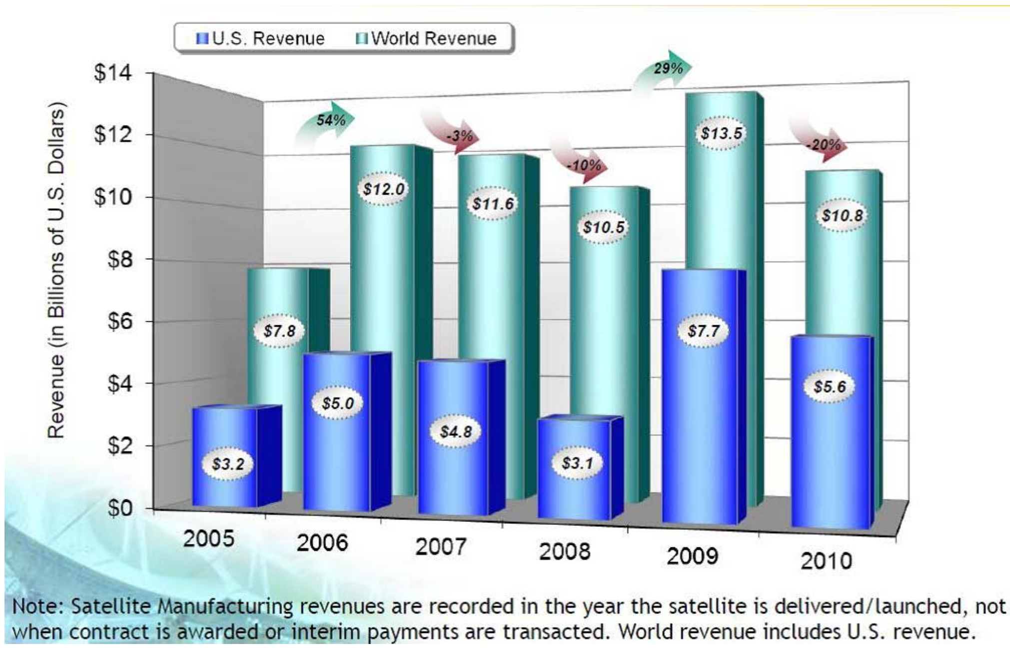


Figure 17. Satellite Manufacturing Revenues
Source: Satellite Industry Association, "Satellite Manufacturing Revenues" (Briefing, State of the Satellite Industry, Washington, DC, June 2011), 17.

The US share of worldwide space related revenues has been waning (figure 17). Since 2005, the US has received less than half of the total worldwide revenue for satellite manufacturing. Even more dramatic is the US share of commercial launch revenue. The US received half of the launch revenue in 2005 but have only received a third of the total revenue since 2006 (figure 18). The US government accounted for over half of the domestic launch revenues during this time (Satellite Industries Association 2011, 20). These facts demonstrate the limited share of the global market the US obtains annually and the general consensus that US leadership in space may be weakening. This is further demonstrated by the number of launches performed over the past several years.

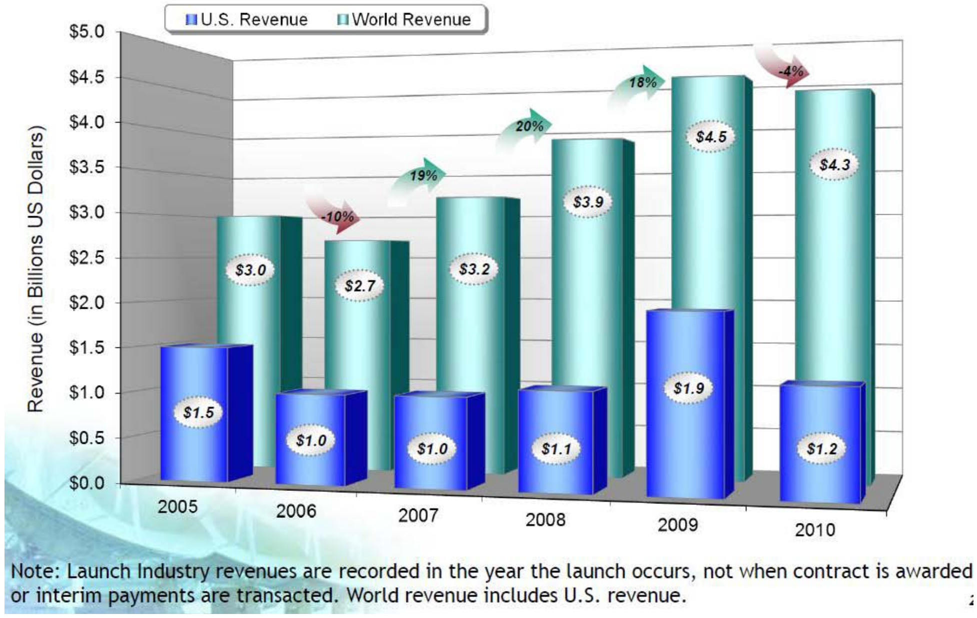
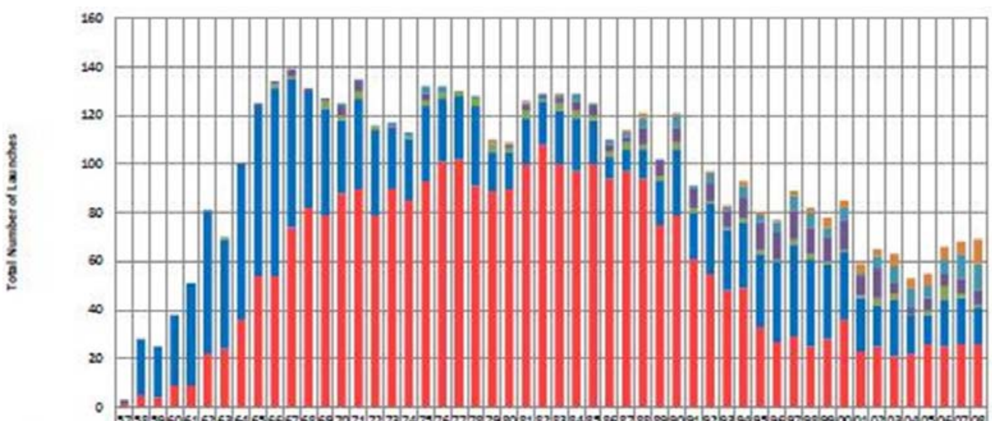


Figure 18. Launch Industry Revenues
Source: Satellite Industry Association, "Launch Industry Revenues" (Briefing, State of the Satellite Industry, Washington, DC, June 2011), 20.



	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82
Other*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0
China	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	2	3	3	0	1	1	0	1	1
Europe	0	0	0	0	0	0	0	0	1	1	3	1	1	4	4	0	1	0	3	0	0	0	0	1	2	1
Japan	0	0	0	0	0	0	1	0	0	2	1	0	3	2	3	2	0	1	2	2	2	3	3	2	3	1
USA	1	23	21	29	42	59	45	64	70	77	61	48	44	30	37	35	25	25	31	26	26	33	16	15	19	18
USSR/Russia**	2	5	4	9	9	22	24	36	54	54	74	82	79	88	90	79	90	85	93	10	10	91	89	90	10	10

	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08
Other*	1	0	0	0	1	2	0	1	0	1	1	2	1	1	2	2	4	3	4	3	5	4	5	5	5	10
China	1	3	1	2	2	4	0	5	1	4	1	5	3	4	6	6	4	5	1	5	7	8	5	6	10	11
Europe	2	4	4	3	2	7	7	6	8	7	7	8	11	11	12	11	10	12	8	12	4	3	5	5	6	6
Japan	3	3	2	2	3	2	2	3	2	1	1	2	2	1	2	2	1	1	1	3	3	0	2	6	2	1
USA	22	22	18	9	9	12	18	27	19	29	25	27	30	33	38	36	31	28	22	17	23	16	12	19	19	15
USSR/Russia**	10	97	10	94	97	94	75	79	61	55	48	49	33	27	29	25	28	36	23	25	21	22	26	25	26	26

† *Chart does not include sub-orbital launches*
* *Other includes Sea Launch*
** *Russia includes launches from Kazakhstan, the major launch port for Russian launch services*

Figure 19. Global Space Launches 1957-2008
Source: John P. Holdren, Office of Science and Technology Policy Pressroom: OSTP Releases assessment of US space launch vehicle engine production capacity, 2009, http://www.whitehouse.gov/galleries/press_release_files/OSTP%20Letter%20on%20Space%20Launch%20Propulsion-12%2022%2009.pdf (accessed 13 May 2011).).

Historical launch rates from 1957 through 2008 have been dominated by the US and Russia (figure 19). Other nations, however, became more active over time. Worldwide launches since 2001 have numbered around 60 launches each year but have been on a steady increase since 2006. US launches during this time have remained less than 25 in a given year with the most occurring in 2003. US launches have also steadily decreased in percentage of worldwide launches since 2006. Domestic launch services accounted for nearly 29 percent of worldwide launches in 2006 but with the increased number of launch services over recent years has dropped to 22 percent of total worldwide launches in 2008.

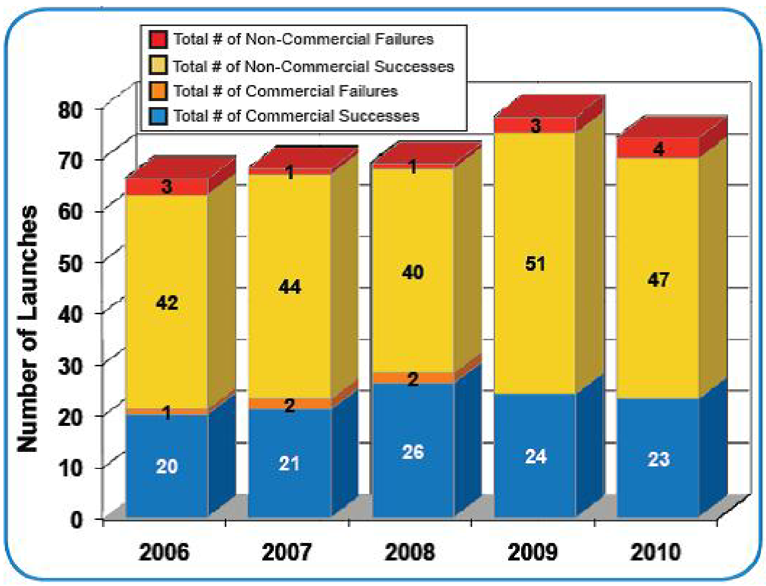


Figure 20. Five-Year Summary of Orbital Launch Events
Source: Federal Aviation Administration, *Commercial Space Transportation: 2010 Year in Review* (Washington, DC: Government Printing Office, January 2011), 16.

The FAA's *Commercial Space Tranndsportation: 2010 Year in Review* highlighted (figure 20) that 355 orbital launches and 17 launch failures took place

worldwide between 2006 and 2010 (Federal Aviation Administration 2011b, 16). This data suggests that approximately 4.8 percent of launches (equating to about three to four launches based on recent annual launch trends) will fail each year (Federal Aviation Administration 2011b, 16). The annual launches performed during this timeframe increased each year from 66 launches in 2006 to 74 launches in 2010. The primary area that additional launches appear to consistently grow is within non-commercial launches. In focusing on the internationally competed launch contracts where launch opportunities are available to any capable launch service provider, the global commercial launch market can be better understood.

Of the 108 internationally competed launch events between 2006 and 2010, Russia, Europe, and Sea Launch AG launched 95 (88 percent) while the US only launched 10 (9.3 percent) with the remaining three performed by China and India (Federal Aviation Administration 2011b, 19). This demonstrates the dependence by domestic launch providers for US government missions as a result of inability to win more commercial business. This may be due to a number of reasons including higher cost for ULA's launch services, the perceived inability to affect the EELV launch schedule filled with US government missions, and policies and agreements that may dictate use of national launch vendors. Foreign launch service providers are dominating the market and making it increasing difficult for US launch service providers to compete. The addition of new entrants (or rejoining entrants), including China, India, Japan, a revamped Sea Launch AG, and SpaceX creates additional friction and competition for commercial business when launch demands are anticipated to grow steadily but not significantly.

Aside from the revenues and launch trends through 2010, a number of significant events occurred in 2010 and 2011 that affect the future of domestic spacelift.

Significant Spacelift Events in 2010 and 2011

Technology proliferation and advancement of spacelift capabilities in recent years have enabled many countries to become spacefaring nations. Over 60 nations and consortiums currently possess space assets. In 2003, China became only the third nation to demonstrate independent manned spaceflight and in 2009, Iran became the ninth spacefaring nation with launch capabilities (Jaramillo 2011, 17). In addition to state-owned advancements made over the past decade, global space launch has slowly increased in recent years (figure 20). In focusing on 2010 and 2011, one can determine the current trends in spacelift and begin to predict what may lay in store for the future of launch services worldwide.

In 2010, Scaled Composites (US-based aerospace company) started test flights of its SpaceShip Two suborbital crew vehicle (prototype for world's first commercial manned spaceship) and SpaceX successfully conducted their inaugural Falcon 9 launch (Federal Aviation Administration 2011c, 3). Like SpaceX, Orbital Sciences Corporation also successfully launched the first Minotaur IV launch vehicle in 2010 (a vehicle based on decommissioned Peacekeeper rocket motors) in order to support launch for a niche of payloads ranging up to 3,800 lbs to LEO (Beneski 2010a). Furthermore, Sea Launch AG officially emerged from Chapter 11 bankruptcy by completing its reorganization process under Rocket and Science Corporation *Energia*'s acquisition of majority ownership (Hennigan 2011b). On 20 January 2011, ULA successfully launched the first Delta IV Heavy launch vehicle from Vandenberg AFB, California, marking the largest rocket ever

to launch from there (United Launch Alliance 2011b). Although a number of successes were achieved, nine launch failures occurred worldwide between January 2010 and 30 September 2011.

The Indian Space Research Organization experienced two failures of their Geosynchronous Satellite Launch Vehicle (the first in April 2010 and the second in December 2010) and destroyed two telecommunications satellites in the process (Kyle 2011). The Russians experienced the most failures during this time with two Proton Breeze M launch failures (one Proton failure in December 2010 destroyed three Glonass navigation satellites and one Proton failure in August 2011 destroyed the Express-AM4 communications satellite), a Rokot Breeze M launch failure (destroyed the GEO 1K-2 navigation satellite), and a Soyuz-U launch failure (destroyed an International Space Station resupply in August 2011) (Kyle 2011). The Korean Advanced Institute of Science and Technology experienced a launch failure of their second Korean Space Launch Vehicle in June 2009, destroying the STSat-2B scientific satellite (Kyle 2011). In March 2011, Orbital Sciences Corporation experienced their second straight Taurus XL launch failure destroying the NASA Glory Earth sensing satellite (Hennigan 2011a) (Beneski 2011). China also experienced a launch failure with its CZ-2C launch vehicle in August 2011 destroying the Shi Jian 11-04 research satellite (Kyle 2011). These failures also demonstrate that although they predominately affected national space assets, they also involve commercial space assets.

Taken as a whole, the space industry will continue to grow. The spacelift industry is also becoming more competitive as additional launch service providers emerge. The launch failures demonstrate the great financial risks associated with spacelift. In focusing

on the advancements recently achieved, in the face of potential launch failure, and with the specific support from the 2010 *National Space Policy* to promote domestic commercial space, domestic commercial launch providers gained ground in the commercial launch market.

Table 2. 2010-2011 SpaceX Contracted Launches

Year Contracted	**Satellite**	**Launch Vehicle**	**Launch Date**
2010	AMOS-6: Space Communications Limited	Falcon 9	Dec 2012
	Space Systems/Loral Satellite	Falcon 9	2012
	Formosat-5: Taiwan's National Space Organization (Taiwan government mission)	Falcon 1	Undetermined
	Iridium's NEXT satellite constellation: Iridium Communications Inc	Falcon 9	2015-2017
	Small satellite market: EADS Astrium (EU missions)	Falcon 1	2011-2015
2011	SES-8: SES SA	Falcon 9	Early 2013
	Thaicom-6: Thaicom PLC	Falcon 9	2013

Source: Created by author with data from Federal Aviation Administration, *2011 Commercial Space Transportation Forecasts*, May 2011, 2; Kirstin Brost, "SpaceX and EADS Astrium announce agreement to bring Falcon 1 launch capabilities to the European Institutional market," 9 September 2011; Space Exploration Technologies Corporation, "SpaceX Press Releases," 30 September 2011.

According to the FAA, SpaceX gained a number of commitments and agreements for launch services during 2010 (table 2). This includes agreements with Space Communications Limited (Falcon 9 launch of AMOS-6 to geosynchronous Earth orbit by December 2012), Space Systems/Loral (Falcon 9 launch of Space Systems/Loral satellite to GTO by 2012), Taiwan's National Space Organization (Falcon 1 launch of Formosat-5), and Iridium Communications Incorporated (Falcon 9 launches for Iridium's NEXT satellite constellation between 2015 and 2017 valued at $492 million) (Federal Aviation Administration 2011c, 3-4). SpaceX also reached agreement with European Aeronautic Defense and Space Company-Astrium in the fall of 2010 to provide Falcon 1 launch

services supporting small payloads from Europe’s institutional small satellite market through 2015 (Brost 2010). In 2011, SpaceX continued to win commercial launch services to include agreements with Luxembourg’s SES SA for a Falcon 9 launch of SES-8 in early 2013 and with Thaicom Public Limited Company to launch a Falcon 9 to deploy the Thaicom-6 telecommunication satellite in 2013 (Space Exploration Technologies Corp. 2011d).

Table 3. 2010-2011 ULA Contracted Launches

Vendor	Year Contracted	Satellite	Launch Vehicle	Launch Date
LMCLS-ULA	2010	GeoEye-2: GeoEye Inc	Atlas V	2012
	2011	WorldView-3: DigitalGlobe	Atlas V	2014
ULA	2010	MAVEN: NASA (US government mission)	Atlas V	2013
	2011	Boeing’s Commercial Crew Development program test flights: NASA (US government missions)	Atlas V	2015
		Five NASA missions (US government missions)	Delta II	Through 2020
		Twenty-seven DoD missions as proposed in FY12 budget request (US government missions)	Atlas V & Delta IV	Through 2016

Source: Created by author with data from Federal Aviation Administration, *2011 Commercial Space Transportation Forecasts,* May 2011, 4; Lockheed Martin Corporation, “Lockheed Martin Commercial Launch Services selected to launch DigitalGlobe Worldview-3 Earth imaging satellite,” 15 March 2011; United Launch Alliance, “NASA awards launch services contract for MAVEN mission,” 21 October 2010; United Launch Alliance, “Reliable, cost-effective Atlas V chosen by Boeing,” 4 August 2011; Michael Curie and George H. Diller, “NASA modifies launch service contract to add Delta II rocket,” 30 September 2011.

Lockheed Martin Commercial Launch Services also gained two commercial contracts to be carried out by ULA’s Atlas V launch vehicle (table 3). In September 2010, Lockheed Martin agreed to provide launch services with GeoEye Incorporated to launch the GeoEye-2 Earth observation satellite in 2012 (Federal Aviation Administration 2011c, 4). In March 2011, Lockheed Martin agreed to provide launch

services with DigitalGlobe to launch WorldView-3 in 2014 (Lockheed Martin Corporation 2011a). ULA was also awarded a $187 million launch service contract with NASA in October 2010 to launch the Mars Atmosphere and Volatile Evolution spacecraft in November 2013 aboard an Atlas V (United Launch Alliance 2010c). In August 2011, ULA announced that the Atlas V was chosen to support Boeing's commercial human spaceflight program with unmanned and manned test flights anticipated in 2015 (United Launch Alliance 2011a). Most recently on 30 September 2011, ULA gained a contract with NASA to provide Delta II launch services for up to a total of five launches through June 2020 (Curie and Diller 2011).

Table 4. 2010-2011 OSC Contracted Launches

Year Contracted	Satellite	Launch Vehicle	Launch Date
2010	IRIS: NASA (US government mission)	Pegasus XL	Dec 2012
	OCO-2: NASA (US government mission)	Taurus XL	Early 2013

Source: Created by author with data from Orbital Sciences Corporation, "Orbital's Pegasus and Taurus rockets selected to launch two NASA scientific satellites," 1 July 2010.

Aside from SpaceX and ULA, Orbital Sciences Corporation also won NASA launch service contracts to provide a Pegasus XL launch in December 2012 for the Interface Region Imaging Spectrograph spacecraft and to also provide a Taurus XL launch of the Orbiting Carbon Observatory-2 environmental satellite in early 2013 (table 4) (Beneski 2010b). In evaluating Orbital Sciences Corporation's primary business opportunities since 2010, the preponderance of their business resides in design, manufacturing, integration, and delivery of satellites and satellite sub-systems or the use

of small-scale rockets and target vehicles used for DoD missile defense testing (Orbital Sciences Corp. 2011). Most of the payloads designed and manufactured by Orbital Sciences Corporation were awarded to Arianespace SA (Azerspace/Africasat-1A, Commercially Hosted Infrared Payload onboard SES-2, and Mexsat-3) and SpaceX (Iridium NEXT satellites, SES-8, and Thaicom-6) for launch services. In addition to these domestic launch providers, international spacelift providers also garnered significant launch business.

Arianespace SA celebrated its 30th year in the international spacelift business in 2010 while also garnering a total of seven Soyuz launch contracts and twelve Ariane 5 contracts (table 5) (Arianespace SA 2011d). They also signed agreements to provide launch services for the European Space Agency (five Soyuz launches for the first ten Galileo satellites starting in December 2012 and a December 2012 Soyuz launch of the Sentinel-1A satellite as part of the European Global Monitoring for Environment and Security program), French-Italian governments (either an Ariane 5 or Soyuz launch of Athena-Fidus military telecommunications satellite in 2013), OverHorizon Limited Liability Company (Ariane 5 launch of OHO-1 in mid-2012), Hughes Network System Limited Liability Company (Ariane 5 launch of a Ka-Band, high-throughput communications Jupiter satellite in 2012), Intelsat SA (Ariane 5 launch of Intelsat-17 which was successfully launched on 26 November 2010 after only six months from award of the launch contract and an Ariane 5 launch of Intelsat-20 scheduled for 2012), EADS Astrium (Ariane 5 launch of Skynet-5D military telecommunications satellite in 2013), Lockheed Martin Commercial Space Systems (either Ariane 5 or Soyuz launch of Vietnam Posts and Telecommunications Group’s VINASAT-2 in 2012), Argentina

(either Ariane 5 or Soyuz launch of Arsat-1 in mid-2012), Indian Space Research Organization (Ariane 5 launch of GSAT-10 communications satellite in 2012), European Meteorological Satellite Organization (Soyuz launch of Metop-C in 2016), Azerbaijan's International Relations and Accounting Center (Ariane 5 launch of Azerbaijan's first communications satellite, Azerspace/Africa-sat-1A, by the end of 2012), and Telespazio (Ariane 5 launch of Sicral-2 military telecommunications satellite in late 2013) (Arianespace SA 2011e).

In 2011 (1 January through 30 September 2011), Arianespace SA signed agreements with Eutelsat (Ariane 5 launches through mid-2013 for 6 satellites), Argentina (either Ariane 5 or Soyuz launch of Arsat-2 in 2013), Luxembourg's SES SA (Ariane 5 launch of Astra-2E in 2013 and an Ariane 5 launch of Astra-5B in mid-2013), Asia Broadcast Satellite (Ariane 5 launch of ABS-2 in 2013), Telenor Satellite Broadcasting (Ariane 5 launch of Thor-7 by the end of 2013), Hispasat (Ariane 5 launch of Amazonas-3 by 2013), DIRECTV (Ariane 5 launch of DIRECTV-14 and DIRECTV-15 in 2014 with an option of launching another two satellites), European Space Agency (Ariane 5 launch of scientific BepiColombo spacecraft in mid-2014), and Mexico (either Ariane 5 or Soyuz launch of Mexsat-3 in late 2012) (Arianespace SA 2011f). In addition to Arianespace SA, Sea Launch AG is also continuing to gain worldwide commercial business while regaining worldwide confidence from their recent financial woes.

Table 5. 2010-2011 Arianespace SA Contracted Launches			
Year Contracted	**Satellite**	**Launch Vehicle**	**Launch Date**
2010	Ten Galileo satellites: ESA (EU missions)	Soyuz	Starting in Dec 2012
	Sentinel-1A: ESA (EU mission)	Soyuz	Dec 2012
	Athena-Fidus satellite: Athena-Fidus (France & Italy government partnership mission)	Soyuz or Ariane 5	2013
	OHO-1: OverHorizon LLC	Ariane 5	2012
	Jupiter satellite: Hughes Network System LLC	Ariane 5	2012
	Intelsat-17: Intelsat SA	*Ariane 5*	*26 Nov 2010*
	Intelsat-20: Intelsat SA	Ariane 5	2012
	Skynet-5D: EADS Astrium (EU mission)	Ariane 5	2013
	VINASAT-2: LMCLS (Vietnam government mission)	Soyuz or Ariane 5	2012
	Arsat-1: Argentina (Argentina government mission)	Soyuz or Ariane 5	2012
	GSAT-10: ISRO (India government mission)	Ariane 5	2012
	METOP-C: European Meteorological Satellite Org (EU mission)	Soyoz	2016
	Azerspace/Africasat-1A: Azerbaijan's International Relations & Accounting Center (Azerbaijan government mission)	Ariane 5	2012
	Sircral-2: Telespazio	Ariane 5	2013
2011	Six Eutelsat satellites	Ariane 5	Through 2013
	Arsat-2: Argentina (Argentina government mission)	Ariane 5	2013
	Astra-2E: SES SA	Ariane 5	2013
	Astra-5B: SES SA	Ariane 5	2013
	ABS-2: Asia Broadcast Satellite	Ariane 5	2013
	Thor-7: Telenor Satellite Broadcasting	Ariane 5	2013
	Amazonas-3: Hispasat	Ariane 5	2013
	DIRECTV-14: DIRECTV	Ariane 5	2014
	DIRECTV-15: DIRECTV	Ariane 5	2014
	BepiColombo: ESA (EU mission)	Ariane 5	2014
	Mexsat-3: Mexico (Mexico government satellite)	Soyuz or Ariane 5	2012

Source: Created by author with data from Arianespace SA, "Continued leadership, 2011 the Arianespace family takes shape," 4 January 2011; Arianespace SA, "Press Release-2010 Archive," 30 September 2011; Arianespace SA, "Press Release-2011 Archive," 30 September 2011.

Sea Launch AG signed launch agreements in 2010 with Asia Satellite Telecommunications Company Limited (Zenit-3SL launch for AsiaSat to GTO between 2012 and 2014) and EchoStar Satellite Services Limited Liability Company (Zenit-3SL launches for up to three EchoStar satellites) (table 6) (Federal Aviation Administration 2011c, 4). In 2011, Sea Launch AG also made agreements with Intelsat SA to launch

Intelsat-18 in late 2011 via Land Launch and Intelsat-19 in 2012 (Sea Launch AG 2011e). While Sea Launch AG continues to regain commercial launch confidence, ILS is also gaining worldwide commercial business.

Table 6. 2010-2011 Sea Launch AG Contracted Launches

Year Contracted	Satellite	Launch Vehicle	Launch Date
2010	AsiaSat: Asia Satellite Telecommunications Company	Zenit-3SL	2012-2014
	Three EchoStar satellites: Echostar Satellite Services LLC	Zenit-3SL	2015
2011	*Intelsat-18: Intelsat SA*	*Zenit-3SLB*	*5 Oct 2011*
	Intelsat-19: Intelsat SA	Zenit-3SL	2012

Source: Created by author with data from Federal Aviation Administration, *2011 Commercial Space Transportation Forecasts*, May 2011, 4; Sea Launch AG, "Press Releases," 30 September 2011.

ILS made several launch service agreements in 2010 (table 7). These include agreements with Luxembourg's SES SA (Proton launch of SES-3 and Kazsat-2 satellites in 2011 and a Multiple Launch Agreement for six Proton launches through 2014), Intelsat SA (Proton launch of Intelsat-21 in early 2012 and Intelsat-23 in late 2011), Telesat (Proton launch of Nimiq-6 telecommunication satellite in mid-2012 and a Proton launch of Anik-G1 telecommunication satellite in 2012), Gazprom Space Systems (Proton launches for YAMAL-401 and YAMAL-402 communication satellites between 2012 and 2013), Asia Satellite Telecommunications Company Limited (Proton launch of AsiaSat-7 in 2011), and *Satélites Mexicanos Sociedad Anonima de Capital Variable* (Proton launch of Satmex-8 in 2012) (International Launch Services Inc. 2011f).

In 2011, ILS also agreed to support launch services for Luxembourg's SES SA (Proton launch of SES-6 in 2013), Mitsubishi Electric Corporation (Proton launch of

Turksat-4A telecommunication satellite in late 2013 and a Proton launch of Turksat-4B in early 2014), EchoStar Satellite Services Limited Liability Company (Proton launch of EchoStar-XVI in 2012), and Inmarsat Public Limited Company (three Proton launches for three Inmarsat-5 telecommunications satellites to be launched between 2013 and 2014) (International Launch Services Inc. 2011g). In understanding the various launch service contracts identified since 2010, future launch trends can be forecasted.

Table 7. 2010-2011 ILS Contracted Launches

Year Contracted	Satellite	Launch Vehicle	Launch Date
2010	*SES-3 & Kazsat-2: SES SA & Kazakhstan (Kazakhstan government mission)*	*Proton Breeze M*	*16 Jul 2011*
	Six SES satellites: SES SA	Proton Breeze M	2014
	Intelsat-21: Intelsat SA	Proton Breeze M	Early 2012
	Intelsat-23: Intelsat SA	Proton Breeze M	Late 2011
	Nimiq-6: Telesat	Proton Breeze M	2012
	Anik-G1: Telesat	Proton Breeze M	2012
	YAMOL-401: Gazprom Space Systems	Proton Breeze M	2012-2013
	YAMOL-402: Gazprom Space Systems	Proton Breeze M	2012-2013
	AsiaSat-7: Asia Satellite Telecommunications Company	Proton Breeze M	Late 2011
	Satmex-8: Satmex	Proton Breeze M	2012
2011	SES-6: SES SA	Proton Breeze M	2013
	Turksat-4A: Mitsubishi Electric Corporation (Turkey government satellite)	Proton Breeze M	2013
	Turksat-4B: Mitsubishi Electric Corporation (Turkey government satellite)	Proton Breeze M	2014
	EchoStar-XVI: Echostar Satellite Services LLC	Proton Breeze M	2012
	Three Inmarsat satellites: Inmarsat PLC	Proton Breeze M	2013-2014

Source: Created by author with data from International Launch Services Inc., “ILS News Releases-2010,” 30 September 2011; International Launch Services Inc., “ILS News Releases-2011,” 30 September 2011.

2011 Launch Forecast Through 2020

The most recent US government forecast for commercial spacelift demand is published in the May 2011 FAA’s *2011 Commercial Space Transportation Forecasts*. It includes forecasts generated through the Commercial Space Transportation Advisory

Committee, for launches anticipated to geosynchronous orbits, and the FAA's Office of Commercial Space Transportation, for launches projected to non-geosynchronous orbits (including LEO, medium Earth orbit, elliptical orbits, and external orbits beyond the Earth). It is important to note that this launch forecast does not account for state-sponsored launches or scientific launches not procured commercially.

Table 8. Commercial Space Transportation Payload and Launch Forecasts

	2011	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**Total**	**Avg**
Payloads												
GSO Forecast	18	26	23	20	20	20	19	20	20	19	205	20.5
NGSO Forecast	37	31	22	15	45	41	39	15	16	15	276	27.6
Total Payloads	55	57	45	35	65	61	58	35	36	34	481	48.1
Launches												
GSO M to H	14	21	18	15	15	15	14	15	15	14	156	15.6
NGSO M to H	11	11	9	9	15	15	13	9	10	9	111	11.1
NGSO Small	0	2	3	2	2	2	2	2	2	2	19	1.9
Total Launches	25	34	30	26	32	32	29	26	27	25	286	28.6

Source: Federal Aviation Administration, *2011 Commercial Space Transportation Forecasts* (Washington, DC: Government Printing Office, May 2011), 2.

As mentioned in the FAA report, the current forecast is "an average annual demand of 28.6 commercial space launches worldwide from 2011 through 2020" (Federal Aviation Administration 2011a, 1). This is 3.6 percent higher than forecasted in 2010 (predicted 27.6 commercial launches annually) (Federal Aviation Administration 2011a, 1). Of the 28.6 launches anticipated each year, the report projects an average of 15.6 medium-to-heavy launch vehicle launches to geosynchronous orbits, 11.1 medium-to-heavy launch vehicle launches to non-geosynchronous orbits, and another 1.9 small launch vehicle launches to non-geosynchronous orbits (Federal Aviation Administration

2011a, 1). This information is provided in additional detail in table 8. This data also highlights the FAA's anticipated multiple manifest launches where more than one payload is delivered to orbit per launch (approximately five launches per year), such as the dual-manifest approach potentially performed by the Ariane 5 or Proton Breeze M.

In addition to the FAA report, Paris-based Euroconsult also forecasted a 51 percent increase in the number of satellites built for launch during the next decade (Space News 2011a). Euroconsult is anticipating 1,145 satellites being built between 2011 and 2020 and 70 percent of the satellites supporting government requirements for many nations (Space News 2011a). In considering these forecasts, the FAA report also includes factors based on historical launches compared to previous predictions to adjust the near-term launch forecasts to be more accurate.

> Space related projects, like most high technology projects, are susceptible to delays, which tend to make the forecasted demand an upper limit of the number of satellites that might actually be launched. To attempt to account for these differences, a "launch realization factor" has been devised. This factor is based on historical data of actual satellites launched versus predicted satellite demand from previous [geosynchronous orbit] forecasts. This factor has been applied to the near-term forecast in order to provide an idea of the actual number of satellites that may reasonably launch. (Federal Aviation Administration 2011a, 8)

The FAA suggested that a number of aspects are anticipated to affect the future of commercial spacelift. This includes the continuation of spacelift demand to support satellite services. The FAA forecasts a varying flow of payloads and launches to geosynchronous orbits and non-geosynchronous orbits over the next decade (table 8). "[T]he increased globalization of space technology has led not only to the diversification of suppliers and customers for space applications, but also to a sharp reduction in entry barriers to the space domain for many nations" (Jaramillo 2011, 17).

In addition to continuing commercial spacelift needs, an increase in hosted payloads is also forecasted. This approach involves placing secondary systems (potentially owned and operated by other entities) on larger satellites, as host payloads, to share launch costs and help reduce the overall cost for launch (Federal Aviation Administration 2011a, 22). An example of this approach was demonstrated with the DoD Joint Capability Technology Demonstration for the Internet Router in Space payload hosted on the Intelsat-14 telecommunication satellite launched in November 2009 (Pembroke 2009). Michael B. Donley, Secretary of the Air Force, stated that based on the 2010 *National Space Policy* and 2011 *National Security Space Strategy*, the US government has recognized the reality that more partnerships are required in space related activities and that opportunities and possibilities exist for additional hosted payloads (Federal News Service 2011, 11).

Another key aspect affecting the future is the changing landscape of commercial launch services. SpaceX is a new and emerging launch service provider. Orbital Sciences Corporation is marketing the latest Taurus II launch vehicle. Arianespace SA is looking to upgrade the Ariane 5 for additional lift capability while also beginning to offer the Soyuz and Vega launch vehicles from Kourou. ILS is promoting the Proton Breeze M's dual-manifest capability. Sea Launch AG has emerged from bankruptcy and is seeking to reenter the launch market. Additionally, nations like China, Japan, and India are also entering into the launch market (Federal Aviation Administration 2011a, 24-26). Indigenous launch services are treasured national capabilities that will reduce the number of internationally competed commercial launches in the future as nations continue to refine launch capabilities. This will drive launch of domestic payloads in addition to their

national government payloads. One example of this is the Chinese who now launch the APT Satellite Holdings Limited (Hong Kong-based company) commercial telecommunication satellites on the CZ-3 launch vehicles rather than permitting launch services overseas (Federal Aviation Administration 2011a, 25).

The FAA also mentioned that the US government regulatory environment is affecting the future of commercial launch. According to the FAA, the US Department of State reviews and approves export of key satellite components deemed vital to national security to international launch sites under the International Traffic in Arms Regulations (Federal Aviation Administration 2011a, 27). This provided international satellite manufacturers (such as Thales Alenia Space) the need to provide satellites free of restricted US manufactured components and enable launch from international launch service providers not permitted by the State Department (de Selding 2009b). This impacts US satellite manufacturer marketability, which had been a worldwide leader in the industry, and further encourages satellites to be manufactured and launched abroad. Another key aspect affecting the future of commercial launch is the recent global financial woes. "[B]udgetary constraints have proven to be a positive motivator for increased cooperation and interdependence, moving some countries to look for ways to improve their access to and use of existing systems without necessarily launching their own" (Jaramillo 2011, 23).

To place insurance rates in perspective, an example of insurance premiums Eutelsat Communications established with Willis Inspace (insurance broker) in 2008 was evaluated. Rates are dependent on launch vehicle selected with the premiums consisting as a percentage of negotiated launch cost. Ariane 5 was at 6.5 percent, Atlas 5 at 6.6

percent, Sea Launch at 7.5 percent, Chinese Long March at 7.9 percent, and the Russian Proton at 10.3 percent (de Selding 2008). Although somewhat dated, these rates demonstrate the costs for commercial entities to safeguard space-based interests. Financing for satellites and launch services remains under increased scrutiny with the current economic climate. Combined with the anticipated increased demand for satellite-based services, it does not appear that financing will affect current launch services or insurance for launch as drastically as other aspects discussed. China provides an interesting example of recent financing for space-based support. China's growing financial and technical support has enabled international space-based telecommunications. This includes loans to Bolivia, Laos, and Bangladesh to enable joint ventures in constructing and launching each nation's first communications satellites (Jaramillo 2011, 79).

In summation, a tremendous amount of revenue (over $100 billion worldwide) is tied to space-based services and capabilities. This revenue is anticipated to continue growing in the coming years and is based on additional capabilities and replenishment of existing on-orbit systems. Additionally, launch trends for the next ten years are also expected to gradually increase. Domestically, SpaceX is gaining numerous commercial launch contracts and is leading the domestic launch providers while aiding the US in regaining leadership within the launch market. The increase in launch demand is affected by a variety of aspects including growth in international launch service options, the potential increase in hosted payloads, US regulatory restrictions, and global financial instability. These trends demonstrate the increasing commercial need for space launch,

the potential for increased international collaboration to reduce cost and share capabilities, and that 4.8 percent of launches performed each year can be expected to fail.

Confirmatory Study

Because of Ehrlich's exhaustive research on national policies, commercial spacelift vendor capabilities, and other contributing factors, he drew two specific findings. First, he recommended that the DoD establish international cooperation partnerships "with America's economic and military allies to create a more robust and resilient space launch capability" (Ehrlich 2010, 77). Second, Ehrlich suggested that "the time was ripe to modernize regulations and policies" in order for the DoD to implement "a strategy that is potentially not only more effective, but efficient as well" (Ehrlich 2010, 79). In evaluating these findings compared with information gathered within this study, it is possible to confirm whether his findings are credible, accurate, and appropriate to reduce cost for DoD spacelift.

Ehrlich's first recommendation was based on comparing applicable foreign spacelift systems (specifically Arianespace SA, Japan's Aerospace Exploration Agency, and Sea Launch AG) and identifying contributing factors that affect DoD's spacelift approach and US space policies. He confirmed his hypothesis that the potential exists for the DoD to improve upon its spacelift strategy by either striving to establish foreign spacelift partnerships or by taking steps to diversify and expand the US commercial spacelift market (Ehrlich 2010, 76-79). In evaluating Ehrlich's comments, the author confirmed Ehrlich's evaluation and conclusions regarding Arianespace SA's and Sea Launch AG's launch capabilities. Minor discrepancies were noted for specific launch vehicles and launch costs (launch costs may change over time and are not typically

advertised). Ehrlich's evaluation of Japan's Aerospace Exploration Agency launch capabilities was also confirmed but deemed outside the scope of potential vendors used in this study primarily because it is not a commercial entity.

Beyond Ehrlich's launch vendor evaluation, this study concurs with Ehrlich's recommendation for diversifying and expanding the US commercial spacelift market. However, his suggestion to increase international cooperation partnerships is not supported for spacelift. As noted in the 2010 *National Space Policy*, one of the principle goals is to "expand international cooperation on mutually beneficial space activities to: broaden and extend the benefits of space; further the peaceful use of space, and enhance collection and partnership in sharing space-derived information" (The White House 2010b, 4). As directed in the *National Space Policy,* the author confirmed that the DoD has recently initiated several international partnerships relating to space-based capabilities. These include an Australia partnership with the Wideband Global Satellite program (Satellite Today 2007), the installation of a secondary payload onboard a foreign commercial satellite (DoD Joint Capability Technology Demonstration for the Internet Router in Space payload hosted on the Intelsat-14 telecommunication satellite launched in November 2009) (Pembroke 2009), and recent agreements made with France and Australia in support of space situational awareness (Garamone 2011) (Brinton 2010).

In addition to these established international partnerships, the US is also aiming to expand current partnerships to include India. The July 2011 US-India Space Working Group, which included Secretary of State Hillary Clinton and India's External Affairs Minister Somanahalli Mallaiah Krishna, agreed on finalizing arrangements for sharing satellite data on oceans and global weather patterns (Gopalaswamy 2011, 1). Both nations

also agreed to expand on previous collaboration regarding global navigation capabilities through promoting compatibility and interoperability between the US-based GPS and India's Navigation system (Gopalaswamy 2011, 1).

Another example of recent international partnership is the Advanced Extremely High Frequency satellite program. The DoD is the primary user for the survivable, secure, protected communications satellite program but has also partnered with the United Kingdom, Canada, and the Netherlands (Space and Missle Center, Public Affairs Office 2010). This program will support users on the ground, out at sea, in the air, in the joint community, and with our coalition partners involved in the program. Although international partnerships are continuing to be a cornerstone for the *National Space Policy* and the DoD, the author disagrees with Ehrlich's finding that the DoD should embrace "a new strategy of international cooperation to assure the DoD access to space" (Ehrlich 2010, 77). As a key component of DoD space operations, mission assurance was missing in Ehrlich's evaluation.

Ehrlich did not address mission assurance oversight or how it could affect potential launch vendors. Mission assurance requires extensive government oversight and for the EELV provider to thoroughly demonstrate a reliable, fully tested launch vehicle prepared for launch. Historical evidence over the past ten years suggests that the risk of launch failure for a national security asset is increased without the use of mission assurance. As a result, EELV program costs cannot be compared equally to costs associated with other commercial vendors where a significant number of man-hours, test data, and government reviews and approval are required in order to demonstrate the launch vehicle is flight worthy for DoD standards. Additionally, if foreign launch vendors

were used for DoD payloads and the DoD mission assurance philosophy was still required, additional units, personnel, and facilities would be required to oversee launch site activities. Regular technical reviews would also be required and involve international launch vendor senior leaders with DoD general officers and staffs. The author asserts the additional cost and increased time due to mission assurance could ultimately increase vendor launch costs to a level virtually similar to EELV program trends. Although Ehrlich does not necessarily recommend completely moving away from domestic launch capabilities, forming an international cooperation of assured access to space was not determined by the author to be a viable solution. Ehrlich did not fully develop his recommendation on how to apply international partnerships to spacelift. This study evaluated his recommendation by evaluating if the US government could develop partnerships to share launch service providers or if this could best be accomplished through technology sharing.

If Ehrlich's recommendation for international partnership involved sharing launches between launch service providers, then it is presumed costs and launch opportunities would need to be shared. Using the example of the US and Europe, this would involve using ULA and Arianespace SA as the launch service providers. Assuming, all government launch opportunities were pooled for each year, distributed evenly between ULA and Arianespace SA, and the negotiated launch cost was even regardless of launch vendor used, this approach may have merit. Realistically, launch costs would not be shared as each vendor would presumably require their own negotiated launch cost. At current rates, the ULA launch cost is higher per spacecraft than Arianespace SA. In this example, the US also launches more government satellites

annually than Europe. This creates an additional disadvantage for domestic launchers if government launches for the US and Europe are pooled and equally distributed between ULA and Arianespace SA. Domestic providers have historically depended on US government missions while Arianespace SA has predominately depended on commercial launches. This approach could potentially reduce the number of launches for ULA annually and increase the launches available for Arianespace SA. In addition to the affect of launch distribution, resources associated with DoD's mission assurance philosophy would also need to be considered and could significantly affect the use of Arianespace SA. Moreover, this may also negatively affect Arianespace SA's commercial market similar to how ULA is currently affected in the commercial market. In considering the potential drawbacks, this approach is not tenable for national interests or commercial launch service providers.

If Ehrlich's recommendation for international partnership is more focused on launch vehicle technology, then a proper evaluation of current launch vehicles may help provide insight into this proposal. In a way, ULA's Atlas V launch vehicle is probably the most internationally developed in the launch market. With the first-stage engine manufactured in Russia (RD-180) and other minor components manufactured in Europe (such as payload fairings), the Atlas V has proven international partnerships can succeed in the launch market but at increased cost and risk compared to in-house manufacturing and testing like Arianespace SA and SpaceX. Acquiring components from international partners forces launch vehicle manufacturers to remain dependent on foreign component vendor production schedules and quality assurance, component costs are generally higher

than if developed and manufactured in house (like SpaceX), and commercial international components are greatly dependent on political stability between nations involved.

Because of political tensions between the US and Russia over the past decade, exporting engines to the US has become an increasing concern for the DoD. This was addressed by the DoD by having Pratt and Whitney Rocketdyne conduct an extensive coproduction review with *RD AMROSS* that demonstrated Pratt and Whitney Rocketdyne could produce the RD-180 (Space Daily 2003). For now, the EELV program is continuing to stockpile RD-180s manufactured in Russia but can initiate domestic production through Pratt and Whitney Rocketdyne. The cost for procuring the Russian engines can fluctuate and as a result, create increased cost to the Atlas V launch vehicle. Recently, the Russian Comptroller's Office raised concern that RD-180 engines were sold to the US at a rate that was less than the cost of manufacturing (Space News 2011b) (Svitak 2011). This creates additional concern for the future of economically stockpiling RD-180s than investing in establishing a new engine production line in the US to produce the engines. The RD-180 engine highlights the inherent risks and problems encountered in the launch market when tied to international partnerships for critical components.

In addition to Ehrlich's recommendation for greater international partnerships, his second finding was the need for a transformation based on the realities of the domestic space launch industry (Ehrlich 2010, 78). He concluded "the time was ripe to modernize regulations and policies" in order for the DoD to implement "a strategy that is potentially not only more effective, but efficient as well" (Ehrlich 2010, 79). Ehrlich acknowledges the need for a domestic launch capability. He asserts the "current defense industrial base can no longer maintain this capability without significant government subsidies" (Ehrlich

2010, 78). He attributes this finding based on the overwhelming number of US government launches performed by domestic launch providers and the increase in funding since the beginning of the EELV program. The lack of commercial launches performed by EELV program launch vehicles has driven DoD launch costs higher over time. Commercial launches were anticipated to help drive launch costs down when the program started but has since predominately supported US government launches. Ehrlich particularly highlights the rise in EELV program funding since program start. Of particular concern is that DoD launch costs have “increased at a rate of nearly 16.2 percent per year for the past decade” (Ehrlich 2010, 78). Additionally, Ehrlich also mentions that “space launch capability represents 39 percent” of the total space system’s procurement budget (Ehrlich 2010, 14). Based upon current research, the author determined that the overall space system’s procurement budget has increased 163 percent between the FY01 and FY12 DoD budget requests (which equates to the 16.2 percent per year increase Ehrlich referenced) (Harrison 2011, 33).

Unfortunately, this is not indicative of the EELV program budget and was misused when relating to the cost growth of DoD space launch. In reality, the cost grew significantly more for the EELV program but can also be attributed to factors previously identified with the history of the EELV program and particularly for the DoD approach to space launch in FY01. According to the USAF FY01 budget request on procurements, the EELV program sought almost $288 million for three launches in 2001 (Air Force Financial Management and Comptroller 2000a, 5-47). In contrast, the EELV program sought $1.15 billion for three launches in 2011 (Air Force Financial Management and Comptroller 2011a, 05-67). In FY01, the USAF also garnered $333 million in funding for

Research, Development, Test and Evaluation (RDT&E) as the EELV program was still in its infancy (Air Force Financial Management and Comptroller 2000b, 3: 901). Currently, the EELV program is in its sustainment phase and only obtained $30 million in FY11 RDT&E funding for new flight safety and tracking technology (Air Force Financial Management and Comptroller 2011b, 2: 751). As a whole, this demonstrates an EELV procurement increase of over 400 percent between FY01 and FY11. This is primarily attributed to the modified EELV program strategy over the past decade but also to the fact that in FY01, EELV was still mostly a development effort (as highlighted by the significant funding included in RDT&E).

The biggest factor that Ehrlich failed to capture and what creates the dramatic increase between FY01 and FY11 was that the USAF was also continuing with legacy launch vehicle programs in FY01, including the Medium Lift Vehicle programs (involving the Atlas II and Delta II) and the Titan Space Boosters program. In looking at the funding figures for these programs, they combined to nearly $526 million in FY01 procurement (Air Force Financial Management and Comptroller 2000a, 5-43, 5-57). In using these cost figures combined with cost figures for the EELV program and comparing them against the FY11 EELV program costs, it is noted that DoD spacelift costs have not increased from FY01. In combining procurement and RDT&E funding of the FY01 EELV, Medium Lift Vehicle, and Titan Space Booster programs, the study determined the total cost in FY01 was nearly $1.15 billion. In comparing this cost figure with the FY11 total EELV program cost of $1.18 billion, the funding for DoD space launch has actually decreased between FY01 and FY11 when inflation is factored.

This cost comparison does demonstrate the fact that EELV is failing to meet the desired goal of achieving cost savings compared to heritage launch costs but does demonstrate that the EELV program is not deviating from past launch costs. In reality, the EELV program was an unproven program during FY01 and cannot be used as a basis for cost comparison in FY12. In comparing the latest proposed FY12 DoD budget request, EELV program procurement was nearly 46 percent of the space system's procurement request (DoD Office of the Under Secretary of Defense (Comptroller)/CFO 2011). This is slightly higher than the 39 percent Ehrlich noted but is a start by the USAF to institute a block buy approach to procure a steady-state number of launches per year, regardless of projected mission availability (Air Force Financial Management and Comptroller 2011a, 5-67). Because the US government is the primary customer for ULA launch services, it could be seen that the EELV program is subsidizing ULA to maintain domestic launch services. This study agrees with Ehrlich's finding that the EELV program is essentially subsidizing ULA but also determined this is not an isolated case. Other vendors (such as Arianespace SA and ILS) are also benefiting from subsidies beyond the cost for government launches.

In March 2011, ILS was debating whether to submit a formal protest to the World Trade Organization for the European Union's decision to award a two-year aid package of nearly $318 million to Arianespace SA to help them become profitable again (de Selding 2011b). As a result of ILS concerns, Arianespace SA Chief Executive Jean-Yves Le Gall had accused ILS of also receiving subsidies from the Russian government and that hidden subsidies are included with use of the Baikonur Cosmodrome where

thousands of personnel supporting launch operations are actually paid by the Russian government and are provided virtually free to launch vendors (de Selding 2011b).

Other national space launch organizations (such as China and India) are extensions of their respective national government. They may conduct commercial space launches but they do so based on negotiated rates. As demonstrated by these examples, the issue of subsidizing launch services remains prevalent even outside the EELV program. Although the EELV program is presumably one of the most transparent in demonstrating this type of support, both Arianespace SA and ILS are also receiving support in some capacity (both transparent and hidden). If anything, it should be understood that subsidies are part of conducting launch operations, potentially driving why there are so few launch vendors available, and why national governments typically fund their own national space programs. In addition to the cost deviations and subsidies discussed in his study, Ehrlich also determined that the DoD is now in a “state of relying on a single provider to meet its access to space requirements” (Ehrlich 2010, 79). Because of this finding, he asserts that “the nation is one accident away from potentially losing its ability to access space when required” (Ehrlich 2010, 79).

This assertion is dangerous and based strictly on the perception that ULA was formed by merging both The Boeing Company and Lockheed Martin Corporation, the prime launch vendors selected as part of the initial EELV program construct. In reality, ULA was established to consolidate efforts and drive savings. This included consolidating launch vehicle production, engineering, test, and launch operations. Although permitting this merger implies the DoD has placed all its hopes for medium and heavy lift launch requirements toward a single vendor (which is accurate), this argument

fails to appreciate that two unique and distinct launch vehicle families will continue to be produced and used to support EELV program missions. Both the Atlas V and Delta IV were developed from their parent companies but because of the merger, engineering and operations best practices have been identified and standardized across both product lines. By maintaining both the Atlas V and Delta IV family of launch vehicles, the DoD maintains two launch vehicles to safeguard against having a single failure eliminate national security launch capabilities as directed in Title 10 US Code (Office of the Law Revision Counsel, US House of Representatives 2011).

Going beyond the medium and heavy lift launch vehicles, the DoD, National Reconnaissance Office, and NASA have also used other domestic launch vendors for smaller payloads. Examples include the DoD launch of the Space-Based Space Surveillance satellite onboard an Orbital Sciences Corporation Minotaur IV launch vehicle on 26 September 2010 (Ray 2010). The National Reconnaissance Office launched a Rapid Pathfinder Program mission (named NROL-66) onboard an Orbital Sciences Corporation Minotaur I launch vehicle on 6 February 2011 (S. Clark 2011). NASA has also used a variety of small launch vehicles including the launch of the Aeronomy of Ice in the Mesosphere satellite onboard the Orbital Sciences Corporation Pegasus XL launch vehicle on 25 April 2007 (National Aeronautics and Space Administration 2007). These examples highlight the availability of domestic launch support specifically designed for smaller payloads. It also provides an approach that may be used in the event medium or heavy lift launch capability becomes unaffordable or unavailable. It would require satellite design and manufacturing to significantly reduce size and weight of payloads and

constrain each satellite with limited capabilities but small launch vehicles could provide alternative launch options for DoD spacelift.

With the recent demonstration of SpaceX's Falcon family of launch vehicles and to ensure new entrants are fairly considered with EELV launches, the DoD, National Reconnaissance Office, and NASA have also agreed on a new strategy for certifying commercial launch vehicles to compete for EELV class launches in the future (Bunko 2011). As Major Tracy Bunko mentions, this new certification strategy is a cooperative effort "to further enable competition and expand the number of companies who are qualified to launch [EELV-class] missions" (Bunko 2011). This affords the US government the ability to broaden the potential launch vehicle pool beyond the current Atlas V and Delta IV and afford a means for certifying any other new domestic commercial launch vendors that may develop to support EELV-class launches. Based upon maintaining both the Atlas V and Delta IV launch vehicles and the recent developments to unify US government agency's new entrant certification strategy, it is evident that the US government is not precariously close in losing national launch capabilities if a launch failure occurs as Ehrlich argues.

Conclusion

DoD spacelift is based on national policies and standards focused on domestic capabilities and safe, effective spacelift. Through the combination of evaluating DoD's philosophy of mission assurance and the current approach to acquiring spacelift services under the EELV program, the preferred DoD spacelift approach is fully understood. Every aspect of the DoD oversight process involves in-depth spacelift mission assurance. The EELV acquisition program has been modified over time and is currently aiming to

provide flexibility in planning the launch manifest by not tying specific missions to dedicated launch vehicles and also providing ULA and their component manufacturer's consistent assurance and commitment with stable procurement rates (Butler 2011). At the same time, the US Government Accountability Office provided additional recommendations for addressing the latest DoD spacelift acquisition approach by improving its understanding of the domestic industrial base, coordinating efforts across all affected government agencies, ensuring launch mission assurance activities are appropriate, and developing a science and technology plan to improve and evolve launch technologies (Chaplain 2011, 24).

The analysis of six commercial spacelift vendors, including domestic and international commercial vendors, highlighted the various launch vehicles and performance capabilities available (see table 1). The cost estimates obtained for this study were ultimately unreliable and depended on a number of variables including the market and component manufacturer. Costs ranged anywhere between \$40 to \$350 million depending on the type of launch capability required. Medium lift costs varied between \$40 to \$180 million while heavy lift costs (only three launch vehicles are commercially available at this time) ranged between \$80 to \$350 million. Costs associated with the current EELV launch provider were confirmed to be higher than other launch services. A key driver for this higher cost was the combined mission assurance requirements levied upon ULA. Through mission assurance and the additional cost, the DoD is able to minimize the possibility of launch failure and increase the opportunity for space-based capability success. This in turn enables potential savings for multimillion dollar payloads and reduces the possibility of sunk cost resulting from a failed launch destroying a costly

payload. Other launch vendors are not impacted with this level of oversight but it is assumed that costs for other vendor launch services would also increase in order to permit the same level of DoD mission assurance oversight. As a result, cost data for launch services must be used cautiously when determining if DoD spacelift requirements can be achieved more efficiently.

The number of launches increased from 66 launches in 2006 to 74 launches in 2010. Of the 108 internationally competed launch events during the period between 2006 and 2010, Russia, Europe, and Sea Launch AG launched 95 (88 percent) while the US only launched 10 (9.3 percent) and the remaining three performed by China and India (Federal Aviation Administration 2011b, 19). Foreign launch service providers currently dominate the launch market and make it increasing difficult for ULA and Orbital Sciences Corporation to compete. The addition of other new entrants, including China, India, Japan, a revamped Sea Launch AG, and SpaceX, creates additional competition for commercial business when launch demands are not growing significantly. As it relates to commercial spacelift demand, over $100 billion of commercial revenue is based on space-based capabilities and that it will continue to grow. Additionally, the number of launches over the next ten years is also expected to increase gradually. Domestically, SpaceX has become the leader in the near-term for domestic-based commercial launch service. It received several commercial launch contracts over the past couple of years.

Hosted payloads may become more common since they involve multiple commercial and government organizations. This approach involves placing secondary systems (potentially owned and operated by other entities) on larger satellites, as host

payloads, to share launch costs and help reduce the overall cost for launch (Federal Aviation Administration 2011a, 22).

In evaluating other launch trends between 2006 and 2010, a total of 355 launches were conducted and a total of 17 launch failures occurred (Federal Aviation Administration 2011b, 16). This leads to nearly three to four launch failures each year (Federal Aviation Administration 2011b, 16). Launch trends suggest an increasing commercial need for space launch, the potential for increased international and corporate collaboration to reduce cost and share capabilities, and that launch failures will continue to occur in the global launch market. Current launch forecasts estimate an average annual demand of 28.6 commercial space launches worldwide between 2011 and 2020 (Federal Aviation Administration 2011a, 1). This includes an average of 15.6 medium-to-heavy launch vehicle launches to geosynchronous orbits, 11.1 medium-to-heavy launch vehicle launches to non-geosynchronous orbits, and another 1.9 small launch vehicle launches to non-geosynchronous orbits (Federal Aviation Administration 2011a, 1). Even Europe's Euroconsult anticipates 1,145 satellites being built during this period. 70 percent will support government requirements (Space News 2011a). Taken as a whole, there are a number of dynamic trends that will affect the future of domestic spacelift.

Ehrlich's thesis was similar to this study. It aimed to determine if the DoD could continue to afford and maintain its current spacelift strategy (Ehrlich 2010, 3). Ehrlich identified two specific recommendations. His first finding was a recommendation that the DoD establish international cooperation partnerships "with America's economic and military allies to create a more robust and resilient space launch capability" (Ehrlich 2010, 77). Although strides have been made by the DoD to expand international

partnership with space-based capabilities, launch with international partnerships was not proven to be tenable in either sharing launch service providers or pushing additional technology sharing. Likewise, Ehrlich also failed to address mission assurance oversight and how it could affect potential international launch vendors if pursued to support DoD spacelift requirements.

Ehrlich's second finding was that "the time was ripe to modernize regulations and policies" in order for the DoD to implement "a strategy that is potentially not only more effective, but efficient as well" (Ehrlich 2010, 79). Ehrlich mentioned the "current defense industrial base can no longer maintain this capability without significant government subsidies" (Ehrlich 2010, 78). His finding was based on perceived subsidies through support from the EELV program. This study determined that transparent or hidden subsidies are prevalent throughout the launch market and almost every launch service provider is being supported in some fashion or form. One major concern was his assertions that DoD launch costs have "increased at a rate of nearly 16.2 percent per year for the past decade" (Ehrlich 2010, 78). In this study, the author identified that the cost increases referenced by Ehrlich were for the total procurement budget of the entire space systems portfolio and not specific to the EELV program. He also failed to capture the legacy systems funding profiles that existed with the EELV program funding profile in FY01 and appropriately compare the amount of funding the DoD utilized for medium and heavy lift missions. Additionally, it was determined that when procurement and RDT&E funding profiles from the FY01 EELV, Medium Lift Vehicle, and Titan Space Booster programs were combined, the total cost in FY01 was nearly $1.15 billion. The total funding profile for the EELV program in FY11was found to be $1.18 billion. This

demonstrated that the funding for DoD space launch has actually decreased between FY01 and FY11 where inflation would have steadily increased launch costs over the past decade. This cost comparison does highlight that EELV is failing to meet the desired goal of achieving cost savings compared to heritage launch costs but that it is not straying from FY01 DoD spacelift costs.

In sum, this chapter answered the secondary research questions posed in this study and aided in determining if DoD spacelift requirements can be achieved in a more efficient approach without reducing the success rates or launch production rates realized under the current EELV program. If EELV program funding is considered a subsidy for ULA, both Arianespace SA and ILS also receive support in some capacity (both transparent and hidden). In addition to historical funding and subsidies, Ehrlich also asserted that the DoD is now in a “state of relying on a single provider to meet its access to space requirements” (Ehrlich 2010, 79). He insisted “the nation is one accident away from potentially losing its ability to access space when required” (Ehrlich 2010, 79). By maintaining both the Atlas V and Delta IV launch vehicles and given recent developments to generate a new entrant certification strategy for EELV-class launches, it is evident that the US government is not as close to losing its national launch capability due to a launch failure as Ehrlich contends. This study also found that the US government aims to expand launch options while maintaining the current EELV program in order to preserve a robust and resilient space launch capability for national interests.

CHAPTER 5

RECOMMENDATIONS AND CONCLUSIONS

> Our objectives are to improve safety, stability, and security in space; to maintain and enhance the strategic national security advantages afforded to the United States (US) by space; and to energize the space industrial base that supports US national security. Achieving these objectives will mean not only that our military and intelligence communities can continue to use space for national security purposes, but that a community of nations is working toward creating a sustainable and peaceful space environment to benefit the world for years to come.
>
> —Robert M. Gates and James R. Clapper,
> *2011 National Security Space Strategy*

The modern world and the DoD are becoming increasing dependent on space-based capabilities. Capabilities such as satellite communications; position, navigation, and timing; environmental monitoring; intelligence, surveillance, and reconnaissance; and early warning are all vital for successful military operations. As a result, a robust spacelift capability is required to not only enable space-based capabilities but it is also a key aspect to safeguard our national security. Significant recent interests in evaluating the EELV program highlight the need to not only gain a better understanding of the costs but also the importance of safeguarding DoD's spacelift capability. The focus of this study was to determine if the DoD can conduct spacelift in a manner that is more efficient or through an approach that reduces time, resources, and complexity while maintaining the current program manufacturing and launch performance effectiveness. In order to address this issue, this study reviewed DoD's spacelift doctrine, identified the DoD's mission assurance philosophy, explored other commercial launch service alternatives, evaluated recent launch trends, uncovered anticipated launch forecasts, and conducted a confirmatory study of a similar thesis. The findings and recommendations described in

this chapter will enable the DoD to understand the current policies and guidelines for spacelift, the commercial spacelift environment, and what may be expected in the coming years.

Interpretation of Findings

Five key findings stand out. First, the status of the commercial launch market and the industrial base to support that market is dynamic but limited. Second, the costs for commercial spacelift services are difficult to calculate and compare. Third, commercial launch vehicles are available to support EELV-type payload requirements but may not necessarily operate at the reliability rate required. Fourth, a variety of launch trends affect spacelift services including escalating revenues, increases in annual launch demand, growth in launch service providers, US regulatory restrictions, and global financial instability. Finally, it is anticipated that over the next decade launch demand will continue to increase and domestic launch providers are beginning to gain ground in the commercial launch market.

The US still maintains a proven and competitive domestic space launch industry with ULA and Orbital Sciences Corporation. SpaceX is a new emerging domestic spacelift vendor that may be capable of providing reliable launch services at much cheaper rates. This will be seen in the coming years as SpaceX continues to demonstrate the reliability and success of the Falcon 9 launch vehicle family through launches already contracted in the commercial market. The DoD and other US government agencies are taking note of SpaceX's launch services and have already established a new certification strategy "to further enable competition and expand the number of companies who are qualified to launch [EELV-class] missions" (Bunko 2011). This strategy is important in

order to expand domestic launch options to support EELV-class launches. As for rocket engine manufacturers, it was noted that only one domestic company (Pratt and Whitney Rocketdyne) currently provides the vital rocket engines used onboard both ULA's Delta IV and Atlas V launch vehicle families (although the Atlas V also uses a Russian manufactured RD-180 engine that also is procured in partnership through Pratt and Whitney Rocketdyne). Aerojet is also developing capabilities of producing rocket engines, such as the US derivative (AJ26-62) of the Russian designed NK-33, and SpaceX designs and produces its own rocket engines for the Falcon 9 (Merlin and Kestrel). In addition to rocket engines, only two domestic manufacturers (Aerojet and Alliant Techsystems) design and produce solid rocket boosters or motors for domestic launch vendors considered. Both Pratt and Whitney Rocketdyne and the solid rocket booster industry are concerned with the end of the shuttle program. In evaluating the health of the rocket engine and solid rocket booster manufacturers, this segment of the industry is not doing well and may drive costs even higher in the near future without a dramatic increase in launch rates or a US manned spaceflight program. Pratt and Whitney Rocketdyne is considering selling its Rocketdyne division due to doubts about the demand for rocket engines with the end of the Space Shuttle program and the undetermined future of the US manned spaceflight program (Harford Business Journal 2011). Additionally, Alliant Techsystems has cut thousands of jobs in northern Utah due to the end of the STS program and no longer needing to produce the massive solid rocket boosters used on the shuttle (Oberbeck 2011). Without vendors like Pratt and Whitney Rocketdyne, domestic launch providers would be forced to seek engines overseas similar

to the RD-180 engine used on the Atlas V and the NK-33 engine to be used on the Taurus II.

The engine and booster industry may also be hindered by national export policies restricting sales of capabilities overseas. Although this policy is important and well intended to safeguard and prevent the potential proliferation of technologies or identification of vulnerabilities, it also hinders commercial sales. Allies and favored nations may be interested in such technologies and should be permitted to engage with domestic manufacturers on a case-by-case basis. Although, this policy does not directly involve sales of launch vehicle components, it can impact the engine and booster industry. The primarily segment of the space industry affected with export controls is the satellite manufacturing industry. Export controls provided international satellite manufacturers (such as Thales Alenia Space) the motivation to provide satellites free of restricted US manufactured components (de Selding 2009b). As a result, satellite sales will become increasingly competitive and launches may continue to be conducted by international launch service providers over domestic launch service providers. A second-order effect resulting from export controls on satellite manufacturing and additional overseas launches has the potential for additional contraction within the domestic spacelift industry. It could also lead to suppliers terminating engine or booster related product lines all together due to lack of profitability resulting from limited numbers of domestic launches.

The combined review of six domestic and international commercial spacelift vendors identified notional costs, the various launch vehicles available, and their respective performance capabilities. Cost estimates were unreliable and greatly affected

by a number of variables including the market demand and component manufacturer. Costs ranged anywhere between $40 to $350 million depending on the type of launch capability required. Medium lift costs varied between $40 to $180 million while heavy lift costs ranged between $80 to $350 million. Costs associated with the current EELV launch provider were confirmed to be on the higher end. The higher cost was a result of the combined mission assurance requirements levied upon ULA. Other launch vendors are not impacted with this level of oversight. This study assumed costs would dramatically increase for other vendor launch services and additional time would be required for processing and launch preparation to permit the same level of DoD mission assurance oversight and launch success. As a result, cost data for the various launch service vendors was not practical for comparison as originally planned in order to determine if DoD spacelift requirements can be achieved more efficiently.

The six domestic and international commercial spacelift vendors were selected because of the launch vehicle capabilities they offer in meeting EELV program lift requirements. All the launch vendors reviewed provide capable launch vehicles suitable for EELV program requirements with the exception of reliability rates. The EELV program reliability standard is between 97 percent for medium-lift launches and 97.5 percent for heavy-lift launches (Space and Missile Center 2010, 3). Based on historical successes used for calculating reliability rates, domestic launch vendors have not performed over 30 launches for a single launch vehicle family like the Arianespace SA, Sea Launch AG, and ILS have accomplished. Domestic launch services (primarily ULA and SpaceX) have higher reliability rates than international launch vendors. ULA's Atlas V currently operates at a 96 percent reliability rate and the Delta IV currently operates at

100 percent (for the medium configured launch vehicles) and 80 percent (for the heavy configured launch vehicle). SpaceX's Falcon 9 has only had two launches with 100 percent success to date and Orbital Sciences Corporation's Taurus II is has not been demonstrated yet. The reliability rates for the international launch vehicles evaluated are 93 percent for Arianespace SA's Ariane 5, 90 percent for Sea Launch AG's Zenit-3SL, and 92 percent for ILS's Proton Breeze M.

These rates are highly dependent on the number of launches performed and not truly indicative of launch vehicle capability. ULA's reliability may also be attributed to the mission assurance and quality assurance programs demanded that the other launch providers are not either currently required to adhere to or do not utilize. This also leads to an understanding that launch vendors are willing to accept launch failures in order to maintain lower costs for launch services but at great market risk. Sea Launch AG's 2009 bankruptcy filing that resulted from a launch failure in January 2007 highlights this risk. It grounded the Zenit-3SL, caused losses in launch contracts, and nearly $2 billion in unpaid debts (de Selding 2009a). If the US government is willing to accept the higher risk of launch failure, it is possible to reduce EELV costs but this is an extreme approach not advocated as part of this study.

From analysis of the commercial space industry, over $100 billion of worldwide revenue is currently tied to space-based capabilities. This revenue is anticipated to continue growing in the coming years as it has over the past ten years (nearly a three-fold increase over that time). Additionally, launch trends are also expected to gradually increase over the next ten years. SpaceX is leading the domestic launch service market for commercial launch services by gaining numerous commercial launch contracts so far.

The increase in launch demand is affected by a variety of aspects including growth in international launch service options, the rising demand for space-based capabilities, US regulatory restrictions, and global financial instability. These trends demonstrate the increasing commercial need for space launch, the potential for increased international collaboration on payloads to reduce cost and share capabilities, and that 4.8 percent of launches performed each year can be expected to fail.

To support the increased demand and growing dependence on space-based capabilities, launch forecasts made in the US and in Europe anticipate increases in the market. The FAA forecasts “an average annual demand of 28.6 commercial space launches worldwide from 2011 through 2020” (Federal Aviation Administration 2011a, 1). Of the 28.6 launches anticipated each year, the FAA projects an average of 15.6 medium-to-heavy launch vehicle launches to geosynchronous orbits, 11.1 medium-to-heavy launch vehicle launches to non-geosynchronous orbits, and another 1.9 small launch vehicle launches to non-geosynchronous orbits (Federal Aviation Administration 2011a, 1). In addition to the FAA, Paris-based Euroconsult also forecasts a 51 percent increase in the number of satellites built for launch during the next decade (Space News 2011a). They anticipate 1,145 satellites being built between 2011 and 2020 and 70 percent of the satellites supporting government requirements for many nations (Space News 2011a). These forecasts highlight the demand growth and potential for additional competition, but it must be used carefully. As demonstrated in the early-2000s, launch forecasts failed to emerge creating an EELV program philosophy that failed to deliver on cost savings.

Recommendations

There are options to modify DoD's spacelift approach to be cheaper and more effective. Recommended changes from this study include launch planning modifications through a dual-manifest approach, improving satellite development through host-payload options, reinvigorating satellite on-time delivery rates, maintaining dependence on domestic launch services by expanding options as they become available, and consolidating all US government launch services under DoD oversight. One additional option that is pertinent but not advocated through this study is for the DoD to accept higher risk of launch failure in order to maintain low costs for commercial spacelift. In addition to these options, there are also a number of areas of further study that could also add yield improvements to DoD spacelift efficiency. These include ways to incentivize commercial demand to use EELV launch providers, increasing international partnerships on satellites and payloads beyond means identified, potentially teaming with Europe and exclusively using proven overseas launch services, determining if the US and domestic launch vendors are actively seeking a potential "game-changer" technology for spacelift, identifying impacts to the EELV program if its launch vehicles also support future US manned spaceflight, and evaluating the current mission assurance employed across the EELV program to quantify the true cost of applying this philosophy. The recommended options and the other areas identified for further study can greatly influence DoD's ability to conduct spacelift in a manner that reduces time, resources, and complexity while maintaining the current program manufacturing and launch performance effectiveness.

Recommended Changes to DoD's Spacelift Approach

Dual-manifesting of launches onboard capable launch vehicles is one method of reducing launch costs. Like Arianespace SA and ILS, dual-manifesting affords the ability to launch two satellites into orbit per launch. The advantages associated with this approach include minimizing the specialty-configured launch vehicles and launch costs through a single launch supporting two satellite deployments. This also includes increased risk, however, to destroy or damage multiple satellites resulting from launch anomalies and the increased risk of launch schedule delays due to compounded readiness preparation resulting from two satellites preparing for launch in parallel. This approach effectively standardizes the size and weight for each satellite, standardizes the launch vehicle configuration (in essence eliminating specialized launch vehicles that may use additional solid rocket boosters or motors for launch), and could also be used to help incentivize the commercial satellite market to use EELV launch vehicles.

The drawbacks with this approach include a loss of flexibility, the need to have both satellites prepared for launch at the same time, and the requirement for the launch vehicle to be robust and capable of supporting delivery of multiple satellites. The satellite industry has had issues in delivering satellites prepared for launch on time. This has particularly been a consistent issue for US government satellites. This issue was most recently highlighted with the 28 October 2011 launch of the National Polar-Orbiting Operational Environmental Satellite System Preparatory Project by a Delta II launch vehicle that was originally scheduled for launch in 2006 (Associated Press 2011). Due to technical issues in satellite development, the launch date slipped five years. If two or more satellites are tied together for a single launch, a single satellite delay will delay

launch for all the satellites scheduled on that particular mission. As a result, this delays space-based capabilities achieving orbit when desired and causes additional costs to store or continue processing the satellites. Because of Arianespace SA's experience with dual-manifesting, recent financial losses, and increasing issues in finding suitable satellites to pair for launch, they have started to reevaluate this approach (de Selding 2011a). They also believe this approach is in peril due to Arianespace SA's market forecasts that highlight the potential growth of heavier satellites outpacing smaller telecommunication satellites that are best suited for dual-manifest launches. To ultimately enable this approach, improvements must be made on DoD satellite development to meet on time delivery at the launch site, launch vendors must identify and anticipate the projected growth in satellite size and weight, and modifications must be designed and made to the launch vehicles to support dual-manifest. If these actions are conducted and the risks associated with this approach are mitigated through mission assurance, this new approach has the potential to reduce launch cost resulting in incentivizing the commercial market to select the EELV launch provider.

Another approach that is similar to dual-manifesting is expanding the host payload option. The host payload approach involves placing secondary systems on larger satellites, as host payloads. Secondary systems could potentially be owned and operated by organizations or companies other than the primary satellite owner and operator. Like in dual-manifesting, this enables shared launch costs and helps reduce the overall cost for launch (Federal Aviation Administration 2011a, 22). This enables the US government to place limited space-based capabilities on commercial satellites or allied nation government satellites. This approach also allows for proven technologies to be placed

into orbit potentially quicker than if collected with other systems for a single satellite that may experience launch delay due to technology development issues with satellite sub-systems. If the US government applied this approach, it could also be used to help incentivize the commercial market into using the EELV launch provider by sharing cost of launch. The DoD used this host payload approach with the DoD Joint Capability Technology Demonstration for the Internet Router in Space payload hosted on the Intelsat-14 telecommunication satellite launched in November 2009 (Pembroke 2009). Moreover, Michael B. Donley stated that the US government has recognized the reality that more partnerships are required in space related activities and that opportunities and possibilities exist for additional hosted payloads (Federal News Service 2011, 11).

In addition to changing the DoD's approach to spacelift through dual-manifest and host-payload options, another area that warrants significant attention is on-time payload delivery. As highlighted with the 28 October 2011 launch of the National Polar-Orbiting Operational Environmental Satellite System Preparatory Project, launch delays are a constant issue with US government satellites (Associated Press 2011). All acquisition programs must balance cost, schedule, performance, and risk to be successful. Space systems have typically allowed schedules to slip and costs to rise to minimize risk and achieve performance. This is particularly pronounced for space systems compared to other DoD acquisition programs for terrestrial systems because space systems only have one spacelift opportunity and cannot typically be modified or upgraded once in orbit (exception are software modifications and upgrades that may be achieved). If US government satellites are capable of being delivered on time, launches are more likely to become steady state and can help eliminate some of the erratic nature of EELV

manufacturing that have primarily supported on-demand requirements. Additionally, if payload development and delivery is in concert with the current proposed EELV procurement strategy of acquiring a consistent number of launch vehicles annually, on-time payload delivery enables improved acquisition outcomes and aids in delivering long run affordability the space community aims to achieve.

Based on current US policies, the US remains committed to maintain dependence on domestic launch services. This study agrees with the current policies and recommends maintaining DoD's spacelift dependence on domestic options. Although a number of overseas options are proven and available, withdrawing from domestic launch services could cause domestic launch services to fold or contract even further. This would further lead to potential loss of spacelift intellectual capital and eliminate national security space freedom of action we've enjoyed for several decades. The introduction of SpaceX and Orbital Sciences Corporation's Taurus II into the launch market adds additional domestic launch service options. As will be seen in the coming years, launch successes will drive the viability of using SpaceX, Orbital Sciences Corporation, or any other launch service providers that could compete for US government launches.

Although current national policies direct the DoD to oversee national security spacelift, NASA has flexibility and freedom to procure spacelift for its missions. The projected fiscal environment for the US government drives the need to further identify areas of redundancy and cooperation. This study advocates spacelift as an area that the US government should consider to consolidate. The DoD and NASA should move to consolidate launch oversight under a single manager and this study recommends having the DoD be the US government executive agent to oversee all unmanned spacelift

requirements and mission assurance oversight. This may be achieved through units and organizations currently involved with the EELV program along with any potential liaisons or shared technical expertise. It may also require expanding the current launch scheduling and forecasting procedures directed in AFSPCI 10-1213 and managed by AFSPC but would only require changes necessary to expand beyond the Eastern Range and Western Range to include other launch sites NASA uses (such as Wallops Island, Virginia and Kodiak Launch Complex, Alaska). NASA currently manages launch requirements through its Launch Services Program. This program is currently responsible for "safe, reliable, cost-effective, and on-schedule processing, mission analysis, and spacecraft integration and launch services for NASA and NASA-sponsored payloads needing a mission on expendable launch vehicles" (National Aeronautics and Space Administration 2005, 1). By transitioning this organizations activity under the DoD, additional continuity is achieved, technical expertise is retained, and all government oversight will fall under a single organization rather than having each government agency maintain its own launch oversight organization. NASA would eliminate manning and resources associated with the Launch Services Program but would maintain continuous involvement as a customer to the DoD for launch services. Furthermore, launch requirements could be better collected and managed to maximize overall US government oversight efficiency and negotiations for launch services.

In addition to the options discussed, another option that could reap significant cost savings (although extremely unfavorable and not advocated) is reducing or eliminating DoD mission assurance oversight. DoD oversight and bureaucracy is heavily involved in launch and has significantly affected the current EELV launch provider. As a result, a

tremendous number of personnel and resources are required in order to achieve the success rates mandated under the EELV program. The primary problem with mission assurance is the difficulty in identifying the proper balance of oversight, resources, and risk. Even the September 2011 US Government Accountability Office report recommended the DoD needs to evaluate its mission assurance philosophy to verify it is sufficient and not excessive (Chaplain 2011, 24). If such a study was able to quantify and identify the proper balance of oversight, resources, and risk, this could be applied to the EELV program to maintain overall success of the program but at minimum mission assurance cost and oversight. If the US government is willing to accept higher risk of launch failure through significant reduction of mission assurance, oversight and bureaucracy could be reduced significantly and the launch provider would regain additional flexibility to determine launch readiness and potentially launch at a higher rate. The obvious drawback is the increased potential for launch failure and a potential return to reliance and trust on the commercial launch provider as was witnessed during the late 1990s. Because of the launch failures that resulted during that time, the AFSPC-led Broad Area Review specifically recommended increased government involvement through mission assurance. Although attractive, a drastic reduction in oversight and potential elimination of mission assurance for the sake of reducing launch cost without fully understanding the DoD's mission assurance requirements is not advocated. Based on past studies and experience over the past ten years, this study recommends the DoD maintain its mission assurance philosophy but based on future evaluations to identify and quantify oversight requirements and resources sufficient to mitigate risk of launch failure.

Recommended Areas of Further Study and Evaluation

Six areas for future study and evaluation are needed. These include evaluating ways to incentivize commercial demand to use EELV launch providers, determining ways to increase international partnerships on satellites and payloads, studying ways to team with European nations in using proven overseas launch services, determining if the US and domestic launch vendors are actively seeking a potential “game-changer” technology for spacelift, evaluating impacts to the EELV program if its launch vehicles also support future US manned spaceflight, and quantifying the true cost of applying the mission assurance philosophy across the EELV program.

A key method to help reduce EELV costs per launch is to have a robust launch program that supports numerous launches. Starting with FY12, the USAF is seeking five annual launches under the EELV program (four for USAF missions and one for the Navy) (Harrison 2011, 52). This includes one heavy launch (involving three booster cores) and four medium launch vehicles. With the DoD aiming to streamline its process by creating a steady-state approach for launch rather than on-demand approach, additional commercial launches would greatly assist in lowering cost through economies of scale. As a result, additional study is needed to determine the “sweet-spot” number of launches required each year to deliver reduced cost per launch comparable to overseas providers like Arianespace SA. Then such a study would also need to evaluate ways to incentivize the US commercial market to use EELV providers in order to fill the launch forecast to achieve the “sweet spot” annual launch rates.

Another area of further study involves international partnerships. The US policies reviewed in this study dictate the need for increased partnerships both commercially and

internationally. This aids in stabilizing costs, improving technological advancement, improving interoperability and compatibility, and promoting mutual benefits across commercial and international partners. Although these policies continue to dictate use of domestic launch providers, further evaluation is needed to determine additional ways the US can establish additional partnerships with allies and favored nations for satellites and space-based capabilities. This is already becoming a key issue for the DoD as partnerships have been established in recent years in the Wideband Global Satellite Communication program and the Advanced Extremely High Frequency satellite program. What is unique about this recommendation for further study, is the ability to eliminate redundant programs (such as unilateral satellite communication programs to become more multilateral joint programs like the Wideband Global Satellite Communications program), pooling resources, increasing interoperability, and leveraging technical expertise. Further study is required to identify potential nations, additional space-based capabilities best for partnership, and if this could drive additional domestic launches.

In looking at areas of further study, another area to consider is regarding eliminating dependence on domestic launch providers. International commercial providers are proven and readily available. Ehrlich recommended establishing foreign spacelift partnerships but failed to describe ways the DoD could accomplish spacelift from international launch providers. Current US policies dictate the use of domestic launch providers but this can be altered if deemed appropriate. To determine if using international commercial launch providers is the most efficient approach, additional analysis is needed to determine ways the DoD could oversee spacelift with international providers, identify if and how DoD satellite processing and integration can occur

overseas, and refine the potential second- or third-order affects identified in this study as potential results of pursuing such an approach. By pursuing overseas launch support, this supports the idea of increased international partnerships but also creates additional issues and problems including the possibility of causing domestic launch service providers to fold. Another area that could reap savings and improve efficiency in the launch industry is technology advancement.

Technological advancements have improved launch vehicle performance, reliability, and manufacturing capabilities since spacelift began in 1957. Tremendous focus was conducted in the early years of spacelift and in refining the systems employed today, but not much was encountered through the course of this research regarding any technological advancement currently pursued. Furthermore, limited funding is being used under the EELV program for RDT&E. This begs the question if research and development is being conducted by commercial launch providers or other government agencies. Further evaluation should determine if US government agencies (including DoD research organizations) and domestic launch providers are actively seeking a "game-changer" capability in the launch industry to reduce production costs, reduce operating costs, or improve launch vehicle capabilities to provide domestic launch services an additional edge in the market.

Internationally, China, India, Iran, Japan, and South Korea are actively pursuing and advancing their respective spacelift capabilities. Additionally, the Russians are currently working on a new launch vehicle family known as the Angara family of rockets (Zak 2011). With the emergence of SpaceX and the ongoing development of Orbital Sciences Corporation's Taurus II, domestic launch providers are actively developing and

refining launch vehicles and production capabilities. Outside the scope of this study was what US government agencies, ULA, or other vendors and suppliers are actively researching or developing to improve spacelift performance, reliability, or to reduce launch costs. Such a study would aid in identifying future potential changes in the industry that could help favor domestic launch providers in the future compared to international providers. This was also noted in the September 2011 Government Accountability Office report that highlighted the need for the DoD to develop a science and technology plan to improve and evolve launch technologies (Chaplain 2011, 24). As Eugene "Gene" Kranz (retired NASA Flight Director and Manager) stated:

> I think it is essential to maintain many of these technologies as a nation so we are capable of protecting and providing for our own people before we start worrying about the peoples of the world. In order to take care of the peoples of the world we need a strong economic base ourselves. I think we can see that today as economies of the world are sinking and rising, we are the stabilizing influence. We are providing the funds to keep those people going. To do this, we need a stable and robust economy ourselves. To do this, we need to continue to develop very new and very advanced technologies. To do this, we have to find difficult objectives to go after because this is the forcing function of tough technologies. I think space is truly the last frontier for the development of very new, advanced technologies. We have been living basically on the seed crop. The technologies of the 60s provided the potential systems of the 70s. The technologies that we developed in the Shuttle and developed through star wars are the ones we are using for this tremendous communications revolution that we got. So I think we have got to figure out where is the research and development coming from that is going to allow us to stay on top of the job. (Kranz 1999)

The fifth recommendation for additional study pertains to second- or third-order affects to the EELV program from US manned spaceflight. With the end of the Space Shuttle program, NASA is without a manned spaceflight program for the first time in its history. NASA is dependent on the Russians to deliver supplies and US astronauts to the international space station. NASA is starting to evaluate a future launch vehicle to resurrect US manned spaceflight and to potentially get astronauts to Mars. Additionally,

NASA is using the Commercial Crew Development program to provide small amounts of funding to companies for commercial development and demonstration of crew capsules that could be used for manned spaceflight. The Boeing Company is designing and actively developing the Crew Space Transportation-100 spacecraft as an entrant in NASA's program. In August 2011, Boeing announced selection of the ULA Atlas V launch vehicle to support four test flights of the spacecraft (Harwood 2011). With this development, manned spaceflight may be another concern for the EELV program. Although beyond the scope of this study, further evaluation is needed to determine potential impacts to the EELV program if EELV launchers (like the Atlas V) are used for manned spaceflight in addition to unmanned DoD missions. The US Government Accountability Office also noted affects of efforts relating to NASA's future heavy-lift launch program and the need for the DoD to work closely with NASA in order to maximize government investments for future EELV launch contracts (Chaplain 2011, 24).

Finally, as previously identified in this study, costs associated with DoD mission assurance are unknown but are presumed to drive the higher cost for EELV launches compared to other commercial competitors. Additional evaluation is needed to quantify mission assurance currently employed within the EELV program to maintain the DoD's assured access to space. This assessment would greatly aid in identifying true cost of the EELV program, potentially identify the appropriate amount of mission assurance required to maintain mission success, and even lead to identifying areas of redundancy or non-value added oversight. This is particularly important if the US government intends to expand launch options to other domestic launch providers, such as SpaceX or Orbital

Sciences Corporation, and maintain mission assurance oversight as currently employed within the EELV program. This could then be used to incentivize launch service providers to find ways to achieve mission success at lower cost.

Conclusions

The DoD is facing a fiscally constrained environment. Potentially significant decisions relating to funding cutbacks are on the horizon for all US government agencies. These circumstances force the DoD to accomplish all its missions more efficiently while maintaining its current effectiveness. Military necessity for space-based capabilities continues to drive the need for spacelift but DoD spacelift must be evaluated for any savings or efficiencies. Through an in-depth evaluation of US policies, DoD's spacelift doctrine, DoD's mission assurance philosophy, commercial launch service alternatives, recent launch trends, anticipated launch forecasts, and a confirmatory study of Ehrlich's thesis, a number of conclusions standout.

First, the commercial launch industrial base is limited and is impacted by dynamic market forces. Forecasts and recent trends indicate a growing need for space-based capabilities and launch services. Although this demand is favorable, national governments around the globe continue to subsidize the industry. The launch business is also very unforgiving as demonstrated by Sea Launch AG's bankruptcy. This dynamic environment makes it difficult to accurately evaluate launch providers and identify potential cost savings.

Another key conclusion was that the US government has already performed a number of actions to aid in improving DoD's approach with spacelift services. This includes certifying emerging launch vendors for EELV-class launches, programming

consistent EELV funding through the DoD's Future Years Defense Program, and moving forward with recommendations from several recent US government studies. Recent US government collaboration and actions enabled potential expansion of the DoD's launch vehicle pool beyond the current Atlas V and Delta IV through new means of certifying new domestic commercial launch vendors that may support EELV-class launches. Additionally, the FY12 DoD budget aims to stabilize the industrial base while procuring launch services through a committed block-buy approach and delaying assignment of satellite missions until closer to the launch dates. This commitment ensures stable production rates. The most recent Government Accountability Office report also advocates a number of executive actions before the DoD invests into a new acquisition approach (Chaplain 2011, 24). The DoD has already initiated a number of the recommended executive actions and anticipates completing them in time to support any decision to finalize and execute a revised procurement strategy (Bernstein 2011). These actions enable the EELV program to broaden its domestic launch vehicle options, maintain a consistent funding profile, drive stability in the program, and aid in reducing cost while ensuring mission success.

A third conclusion is that other launch providers are suitable and available to support DoD spacelift requirements. If the US government deems it appropriate to go overseas for launch services, domestic launch providers could potentially fold and create an environment of complete reliance on international partnerships to deliver space-based capabilities. SpaceX and Orbital Sciences Corporation are emerging to provide additional options for the DoD but the launch vehicles are currently unproven. Their performance will be closely followed over the next two years, as they provide launch for upcoming

NASA missions and commercial customers. Their success will determine whether they are potentially reliable and capable of supporting DoD missions.

As the DoD reduces its budget and maintains critical military capabilities, DoD's spacelift approach can be modified. These recommendations enable the DoD to conduct spacelift in a manner that is more efficient, through an approach that reduces time, resources, and complexity while maintaining the current program manufacturing and launch performance effectiveness. Current cooperation efforts between various government agencies, sound fiscal planning, growth of the domestic launch market, and recent trends and forecasts enable a favorable outlook for the EELV program. National security depends on a reliable launch capability. Without this capability, the DoD no longer possesses domestic access to space and will become dependent on foreign launch support to enable national space-based capabilities. Therefore, it is imperative the DoD maintains domestic launch capabilities to safeguard our nations assured access to space.

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USACGSC
100 Stimson Avenue
Fort Leavenworth, KS 66027-2301

Dr. Tony Mullis
DMH
USACGSC
100 Stimson Avenue
Fort Leavenworth, KS 66027-2301

Mr. Thomas Gray
USACGSC
100 Stimson Avenue
Fort Leavenworth, KS 66027-2301